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(54) Title: RECOMBINATIONAL CLONING USING NUCLEIC ACIDS HAVING RECOMBINATION SITES

(57) Abstract

Recombinational cloning is provided by the use of nucleic acids, vectors and methods, *in vitro* and *in vivo*, for moving or exchanging segments of DNA molecules using engineered recombination sites and recombination proteins to provide chimeric DNA molecules that have the desired characteristic(s) and/or DNA segment(s).

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Recombinational Cloning Using Nucleic Acids Having Recombination Sites

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to recombinant DNA technology. DNA and vectors having engineered recombination sites are provided for use in a recombinational cloning method that enables efficient and specific recombination of DNA segments using recombination proteins. The DNAs, vectors and methods are useful for a variety of DNA exchanges, such as subcloning of DNA, *in vitro* or *in vivo*.

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Related Art

Site-specific recombinases. Site-specific recombinases are proteins that are present in many organisms (e.g. viruses and bacteria) and have been characterized to have both endonuclease and ligase properties. These recombinases (along with associated proteins in some cases) recognize specific sequences of bases in DNA and exchange the DNA segments flanking those segments. The recombinases and associated proteins are collectively referred to as "recombination proteins" (see, e.g., Landy, A., *Current Opinion in Biotechnology* 3:699-707 (1993)).

Numerous recombination systems from various organisms have been described. See, e.g., Hoess *et al.*, *Nucleic Acids Research* 14(6):2287 (1986); Abremski *et al.*, *J. Biol. Chem.* 261(1):391 (1986); Campbell, *J. Bacteriol.* 174(23):7495 (1992); Qian *et al.*, *J. Biol. Chem.* 267(11):7794 (1992); Araki *et al.*, *J. Mol. Biol.* 225(1):25 (1992); Maeser and Kahnmann *Mol. Gen. Genet.* 230:170-176 (1991); Esposito *et al.*, *Nucl. Acids Res.* 25(18):3605 (1997).

Many of these belong to the integrase family of recombinases (Argos *et al.* *EMBO J.* 5:433-440 (1986)). Perhaps the best studied of these are the

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Integrase/att system from bacteriophage λ (Landy, A. *Current Opinions in Genetics and Devel.* 3:699-707 (1993)), the Cre/loxP system from bacteriophage P1 (Hoess and Abremski (1990) In *Nucleic Acids and Molecular Biology*, vol. 4. Eds.: Eckstein and Lilley, Berlin-Heidelberg: Springer-Verlag; pp. 90-109), and the FLP/FRT system from the *Saccharomyces cerevisiae* 2 μ circle plasmid (Broach *et al.* *Cell* 29:227-234 (1982)).

5 While these recombination systems have been characterized for particular organisms, the related art has only taught using recombinant DNA flanked by recombination sites, for *in vivo* recombination.

10 Backman (U.S. Patent No. 4,673,640) discloses the *in vivo* use of λ recombinase to recombine a protein producing DNA segment by enzymatic site-specific recombination using wild-type recombination sites attB and attP.

15 Hasan and Szybalski (*Gene* 56:145-151 (1987)) discloses the use of λ Int recombinase *in vivo* for intramolecular recombination between wild type attP and attB sites which flank a promoter. Because the orientations of these sites are inverted relative to each other, this causes an irreversible flipping of the promoter region relative to the gene of interest.

20 Palazzolo *et al.* *Gene* 88:25-36 (1990), discloses phage lambda vectors having bacteriophage λ arms that contain restriction sites positioned outside a cloned DNA sequence and between wild-type loxP sites. Infection of *E. coli* cells that express the Cre recombinase with these phage vectors results in recombination between the loxP sites and the *in vivo* excision of the plasmid replicon, including the cloned cDNA.

25 Pósfai *et al.* (*Nucl. Acids Res.* 22:2392-2398 (1994)) discloses a method for inserting into genomic DNA partial expression vectors having a selectable marker, flanked by two wild-type FRT recognition sequences. FLP site-specific recombinase as present in the cells is used to integrate the vectors into the genome at predetermined sites. Under conditions where the replicon is functional, this cloned genomic DNA can be amplified.

30 Bebee *et al.* (U.S. Patent No. 5,434,066) discloses the use of site-specific recombinases such as Cre for DNA containing two loxP sites is used for *in vivo* recombination between the sites.

Boyd (*Nucl. Acids Res.* 21:817-821 (1993)) discloses a method to facilitate the cloning of blunt-ended DNA using conditions that encourage intermolecular ligation to a dephosphorylated vector that contains a wild-type *loxP* site acted upon by a Cre site-specific recombinase present in *E. coli* host cells.

Waterhouse *et al.* (PCT No. 93/19172 and *Nucleic Acids Res.* 21 (9):2265 (1993)) disclose an *in vivo* method where light and heavy chains of a particular antibody were cloned in different phage vectors between *loxP* and *loxP 511* sites and used to transfect new *E. coli* cells. Cre, acting in the host cells on the two parental molecules (one plasmid, one phage), produced four products in equilibrium: two different cointegrates (produced by recombination at either *loxP* or *loxP 511* sites), and two daughter molecules, one of which was the desired product.

In contrast to the other related art, Schlake & Bode (*Biochemistry* 33:12746-12751 (1994)) discloses an *in vivo* method to exchange expression cassettes at defined chromosomal locations, each flanked by a wild type and a spacer-mutated FRT recombination site. A double-reciprocal crossover was mediated in cultured mammalian cells by using this FLP/FRT system for site-specific recombination.

Transposases. The family of enzymes, the transposases, has also been used to transfer genetic information between replicons. Transposons are structurally variable, being described as simple or compound, but typically encode the recombinase gene flanked by DNA sequences organized in inverted orientations. Integration of transposons can be random or highly specific. Representatives such as Tn7, which are highly site-specific, have been applied to the *in vivo* movement of DNA segments between replicons (Lucklow *et al.*, *J. Virol.* 67:4566-4579 (1993)).

Devine and Boeke *Nucl. Acids Res.* 22:3765-3772 (1994), discloses the construction of artificial transposons for the insertion of DNA segments, *in vitro*, into recipient DNA molecules. The system makes use of the integrase of yeast TY1 virus-like particles. The DNA segment of interest is cloned, using standard methods, between the ends of the transposon-like element TY1. In the presence

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of the TY1 integrase, the resulting element integrates randomly into a second target DNA molecule.

5 **DNA cloning.** The cloning of DNA segments currently occurs as a daily routine in many research labs and as a prerequisite step in many genetic analyses. The purpose of these clonings is various, however, two general purposes can be considered: (1) the initial cloning of DNA from large DNA or RNA segments (chromosomes, YACs, PCR fragments, mRNA, etc.), done in a relative handful of known vectors such as pUC, pGem, pBlueScript, and (2) the subcloning of these DNA segments into specialized vectors for functional analysis. A great deal 10 of time and effort is expended both in the transfer of DNA segments from the initial cloning vectors to the more specialized vectors. This transfer is called subcloning.

15 The basic methods for cloning have been known for many years and have changed little during that time. A typical cloning protocol is as follows:

- 15 (1) digest the DNA of interest with one or two restriction enzymes;
- (2) gel purify the DNA segment of interest when known;
- (3) prepare the vector by cutting with appropriate restriction enzymes, treating with alkaline phosphatase, gel purify etc., as appropriate;
- 20 (4) ligate the DNA segment to the vector, with appropriate controls to eliminate background of uncut and self-ligated vector;
- (5) introduce the resulting vector into an *E. coli* host cell;
- (6) pick selected colonies and grow small cultures overnight;
- (7) make DNA minipreps; and
- 25 (8) analyze the isolated plasmid on agarose gels (often after diagnostic restriction enzyme digestions) or by PCR.

30 The specialized vectors used for subcloning DNA segments are functionally diverse. These include but are not limited to: vectors for expressing genes in various organisms; for regulating gene expression; for providing tags to aid in protein purification or to allow tracking of proteins in cells; for modifying the cloned DNA segment (e.g., generating deletions); for the synthesis of probes (e.g., riboprobes); for the preparation of templates for DNA sequencing; for the

identification of protein coding regions; for the fusion of various protein-coding regions; to provide large amounts of the DNA of interest, *etc.* It is common that a particular investigation will involve subcloning the DNA segment of interest into several different specialized vectors.

5 As known in the art, simple subclonings can be done in one day (*e.g.*, the DNA segment is not large and the restriction sites are compatible with those of the subcloning vector). However, many other subclonings can take several weeks, especially those involving unknown sequences, long fragments, toxic genes, unsuitable placement of restriction sites, high backgrounds, impure enzymes, *etc.* Subcloning DNA fragments is thus often viewed as a chore to be done as few times as possible. Several methods for facilitating the cloning of DNA 10 segments have been described, *e.g.*, as in the following references.

15 Ferguson, J., *et al.* *Gene* 16:191 (1981), discloses a family of vectors for subcloning fragments of yeast DNA. The vectors encode kanamycin resistance. Clones of longer yeast DNA segments can be partially digested and ligated into the subcloning vectors. If the original cloning vector conveys resistance to ampicillin, no purification is necessary prior to transformation, since the selection will be for kanamycin.

20 Hashimoto-Gotoh, T., *et al.* *Gene* 41:125 (1986), discloses a subcloning vector with unique cloning sites within a streptomycin sensitivity gene; in a streptomycin-resistant host, only plasmids with inserts or deletions in the dominant sensitivity gene will survive streptomycin selection.

25 Accordingly, traditional subcloning methods, using restriction enzymes and ligase, are time consuming and relatively unreliable. Considerable labor is expended, and if two or more days later the desired subclone can not be found among the candidate plasmids, the entire process must then be repeated with alternative conditions attempted. Although site specific recombinases have been used to recombine DNA *in vivo*, the successful use of such enzymes *in vitro* was expected to suffer from several problems. For example, the site specificities and efficiencies were expected to differ *in vitro*; topologically-linked products were expected; and the topology of the DNA substrates and recombination proteins was 30 expected to differ significantly *in vitro* (see, *e.g.*, Adams *et al.*, *J. Mol.*

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Biol. 226:661-73 (1992)). Reactions that could go on for many hours *in vivo* were expected to occur in significantly less time *in vitro* before the enzymes became inactive. Multiple DNA recombination products were expected in the biological host used, resulting in unsatisfactory reliability, specificity or efficiency of subcloning. Thus, *in vitro* recombination reactions were not expected to be sufficiently efficient to yield the desired levels of product.

Accordingly, there is a long felt need to provide an alternative subcloning system that provides advantages over the known use of restriction enzymes and ligases.

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SUMMARY OF THE INVENTION

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The present invention provides nucleic acids, vectors and methods for obtaining amplified, chimeric or recombinant nucleic acid molecules using recombination proteins and at least one recombination site, *in vitro* or *in vivo*. These methods are highly specific, rapid, and less labor intensive than standard cloning or subcloning techniques. The improved specificity, speed and yields of the present invention facilitates DNA or RNA cloning or subcloning, regulation or exchange useful for any related purpose.

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The present invention relates to nucleic acids, vectors and methods for moving or exchanging nucleic acid segments (preferably DNA segments or fragments) using at least one recombination site and at least one recombination protein to provide chimeric DNA molecules which have the desired characteristic(s) and/or DNA segment(s). Use of the invention thus allows for cloning or subcloning such nucleic acid molecules into a variety of vectors. Generally, one or more parent nucleic acid molecules (preferably DNA molecules) are recombined to give one or more daughter molecules, at least one of which is the desired Product molecule, which is preferably a vector comprising the desired nucleic acid segment. The invention thus relates to nucleic acid molecules, vectors and methods to effect the exchange and/or to select for one or more desired products.

One embodiment of the present invention relates to a method of making chimeric molecule, which comprises

(a) combining *in vitro* or *in vivo*

5 (i) one or more Insert Donor molecules comprising a desired nucleic acid segment flanked by a first recombination site and a second recombination site, wherein the first and second recombination sites do not substantially recombine with each other;

10 (ii) one or more Vector Donor molecules comprising a third recombination site and a fourth recombination site, wherein the third and fourth recombination sites do not substantially recombine with each other; and

15 (iii) one or more site specific recombination proteins capable of recombining the first and third recombinational sites and/or the second and fourth recombinational sites;

thereby allowing recombination to occur, so as to produce at least one cointegrate nucleic acid molecule, at least one desired Product nucleic acid molecule which comprises said desired segment, and optionally a Byproduct nucleic acid molecule; and then, optionally,

20 (b) selecting for the Product or Byproduct DNA molecule.

In another embodiment, the present invention relates to a method of making chimeric molecule, which comprises

25 (a) combining *in vitro* or *in vivo*

(i) one or more Insert Donor molecules comprising a desired nucleic acid segment flanked by two or more recombination sites wherein said recombination sites do not substantially recombine with each other;

(ii) one or more Vector Donor molecules comprising two or more recombination sites, wherein said recombination sites do not substantially recombine with each other; and

(iii) one or more site specific recombination proteins;

30 (b) incubating said combination under conditions sufficient to transfer one or more said desired segments into one or more of said Vector Donor molecules, thereby producing one or more Product molecules. The resulting Product molecules may optionally be selected or isolated away from other

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molecules such as cointegrate molecules, Byproduct molecules, and unreacted Vector Donor molecules or Insert Donor molecules. In a preferred aspect of the invention, the Insert Donor molecules are combined with one or more different Vector Donor molecules, thereby allowing for the production of different Product molecules in which the nucleic acid of interest is transferred into any number of different vectors in the single step.

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In accordance with the invention, the above methods may be reversed to provide the original Insert Donor molecules which may then be used in combination with one or more different Vector Donor molecules to produce new Product or Byproduct molecules. Alternatively, the Product molecules produced by the method of the invention may serve as the Insert Donor molecules which may be used directly in combination with one or more different Vector Donor molecules, thereby producing new Product or Byproduct molecules. Thus, nucleic acid molecules of interest may be transferred or moved to any number of desired vectors, thereby providing an efficient means for subcloning molecules of interest.

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Thus, the invention relates to combining a Product molecule with a second Vector Donor molecules to produce a second Product molecule. The second Product DNA molecule may then be utilized in combination with a third Vector Donor molecule to produce a third Product molecule. This process of the invention may be repeated any number of times to transfer or move the insert of interest into any number of different vectors. In this aspect of the invention, a combination of two or more different Vector Donor molecules may be combined with the Product molecule to produce in a single step different Product molecules in which the desired nucleic acid segment (derived from the Product DNA molecule) is transferred into any number of different vectors.

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In particular, the present invention relates to a method for cloning or subcloning one or more desired nucleic acid molecules comprising

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(a) combining *in vitro* or *in vivo*

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(i) one or more Insert Donor molecules comprising one or more desired nucleic acid segments flanked by at least two recombination sites, wherein said recombination sites do not substantially recombined with each other;

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(ii) one or more Vector Donor molecules comprising at least two recombination sites, wherein said recombination sites do not substantially recombine with each other; and

(iii) one or more site specific recombination proteins;

5 (b) incubating said combination under conditions sufficient to allow one or more of said desired segments to be transferred into one or more of said Vector Donor molecules, thereby producing one or more Product molecules;

(c) optionally selecting for or isolating said Product molecule;

(d) combining *in vitro* or *in vivo*

10 (i) one or more of said Product molecules comprising said desired segments flanked by two or more recombination sites, wherein said recombination sites do not substantially recombine with each other;

15 (ii) one or more different Vector Donor molecules comprising two or more recombination sites, wherein said recombination sites do not substantially recombine with each other; and

(iii) one or more site specific recombination protein; and

15 (e) incubating said combination under conditions sufficient to transfer one or more of said desired segments into one or more of said different Vector Donor molecules, thereby producing one or more different Product molecules.

20 In accordance with the invention, Vector Donor molecules may comprise vectors which may function in a variety of systems or host cells. Preferred vectors for use in the invention include prokaryotic vectors, eukaryotic vectors or vectors which may shuttle between various prokaryotic and/or eukaryotic systems (e.g. shuttle vectors). Preferred prokaryotic vectors for use in the invention include but are not limited to vectors which may propagate and/or replicate in gram negative and/or gram positive bacteria, including bacteria of the genus *Escherichia*, *Salmonella*, *Proteus*, *Clostridium*, *Klebsiella*, *Bacillus*, *Streptomyces*, and *Pseudomonas* and preferably in the species *E. coli*. Eukaryotic vectors for use in the invention include vectors which propagate and/or replicate in yeast cells, plant cells, mammalian cells, (particularly human), fungal cells, insect cells, fish cells and the like. Particular vectors of interest include but are not limited to cloning vectors, sequencing vectors, expression vectors, fusion vectors, two-

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hybrid vectors, gene therapy vectors, and reverse two-hybrid vectors. Such vectors may be used in prokaryotic and/or eukaryotic systems depending on the particular vector.

The Insert Donor molecules used in accordance with the invention preferably comprise two or more recombination sites which allow the insert (e.g. the nucleic acid segment of interest) of the Donor molecules to be transferred or moved into one or more Vector Donor molecules in accordance with the invention. The Insert Donor molecules of the invention may be prepared by any number of techniques by which two or more recombination sites are added to the molecule of interest. Such means for including recombination sites to prepare the Insert Donor molecules of the invention includes mutation of a nucleic acid molecule (e.g. random or site specific mutagenesis), recombinant techniques (e.g. ligation of adapters or nucleic acid molecules comprising recombination sites to linear molecules), amplification (e.g. using primers which comprise recombination sites or portions thereof) transposition (e.g. using transposons which comprise recombination sites), recombination (e.g. using one or more homologous sequences comprising recombination sites), nucleic acid synthesis (e.g. chemical synthesis of molecules comprising recombination sites or enzymatic synthesis using various polymerases or reverse transcriptases) and the like. In accordance with the invention, nucleic acid molecules to which one or more recombination sites are added may be any nucleic acid molecule derived from any source and may include non naturally occurring nucleic acids (e.g. RNA's; see U.S. Patent Nos. 5,539,082 and 5,482,836). Particularly preferred nucleic acid molecules are DNA molecules (single stranded or double stranded). Additionally, the nucleic acid molecules of interest for producing Insert Donor molecules may be linear or circular and further may comprise a particular sequence of interest (e.g. a gene) or may be a population of molecules (e.g. molecules generated from a genomic or cDNA libraries).

Thus, the invention relates to a number of methods for preparing Insert Donor molecules and the Insert Donor molecules produced by such methods. In one aspect of the invention, primers comprising one or more recombination sites or portions thereof are used in the nucleic acid synthesis or nucleic acid

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amplification to prepare the Insert Donor molecules of the invention. Thus, the invention relates to a method of synthesizing a nucleic acid molecule comprising:

5 (a) mixing one or more nucleic acid templates with a polypeptide having polymerase activity and one or more primers comprising one or more recombination sites or portions thereof; and

10 (b) incubating said mixture under conditions sufficient to synthesize one or more nucleic acid molecules which are complementary to all or a portion of said templates and which comprises one or more recombination sites. In accordance with the invention, the synthesized nucleic acid molecule comprising one or more recombination sites may be used as templates under appropriate conditions to synthesize nucleic acid molecules complementary to all or a portion of the recombination site containing templates, thereby forming double stranded molecules comprising one or more recombination sites. Preferably, such second synthesis step is performed in the presence of one or more primers comprising one or more recombination sites. In yet another aspect, the synthesized double stranded molecules may be amplified using primers which may comprise one or more recombination sites.

15 In another aspect of the invention, one or more recombination sites may be added to nucleic acid molecules by any of a number of nucleic acid amplification techniques. In particular, such method comprises:

20 (a) contacting a first nucleic acid molecule with a first primer molecule which is complementary to a portion of said first nucleic acid molecule and a second nucleic acid molecule with a second primer molecule which is complementary to a portion of said second nucleic acid molecule in the presence 25 of one or more polypeptides having polymerases activity;

25 (b) incubating said molecules under conditions sufficient to form a third nucleic acid molecule complementary to all or a portion of said first nucleic acid molecule and the fourth nucleic acid molecule complementary to all or a portion of said second nucleic acid molecule;

30 (c) denaturing said first and third and said second and fourth nucleic acid molecules; and

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(d) repeating steps (a) through (c) one or more times,
wherein said first and/or said second primer molecules comprise one or
more recombination sites or portions thereof.

In yet another aspect of the invention, a method for adding one or more
5 recombination sites to nucleic acid molecules may comprise:

(a) contacting one or more nucleic acid molecules with one or more
adapters or nucleic acid molecules which comprise one or more recombination
sites or portions thereof; and

(b) incubating said mixture under conditions sufficient to add one or
10 more recombination sites to said nucleic acid molecules. Preferably, linear
molecules are used for adding such adapters or molecules in accordance with the
invention and such adapters or molecules are preferably added to one or more
termini of such linear molecules. The linear molecules may be prepared by any
15 technique including mechanical (e.g. sonication or shearing) or enzymatic (e.g.
nucleases such as restriction endonucleases). Thus, the method of the invention
may further comprise digesting the nucleic acid molecule with one or more
nucleases (preferably any restriction endonucleases) and ligating one or more of
20 the recombination site containing adapters or molecules to the molecule of
interest. Ligation may be accomplished using blunt ended or stick ended
molecules. Alternatively, topoisomerases may be used to introduce recombination
sites in accordance with the invention. Topoisomerases cleave and rejoin nucleic
acid molecules and therefore may be used in place of nucleases and ligases.

In another aspect, one or more recombination sites may be added to
nucleic acid molecules by *de novo* synthesis. Thus, the invention relates to such
25 a method which comprises chemically synthesizing one or more nucleic acid
molecules in which recombination sites are added by adding the appropriate
sequence of nucleotides during the synthesis process.

In another embodiment of the invention, one or more recombination sites
may be added to nucleic acid molecules of interest by a method which comprises:

30 (a) contacting one or more nucleic acid molecules with one or more
integration sequences which comprise one or more recombination sites or portions
thereof; and

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5 (b) incubation of said mixture under conditions sufficient to incorporate said recombination site containing integration sequences into said nucleic acid molecules. In accordance with this aspect of the invention, integration sequences may comprise any nucleic acid molecules which through recombination or by integration become a part of the nucleic acid molecule of interest. Integration sequences may be introduced in accordance with this aspect of the invention by *in vivo* or *in vitro* recombination (homologous recombination or illegitimate recombination) or by *in vivo* or *in vitro* installation by using transposons, insertion sequences, integrating viruses, homing introns, or other integrating elements.

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15 In another aspect, the invention relates to kits for carrying out the methods of the invention and more specifically relates to cloning or subcloning kits and kits for making Insert Donor molecules of the invention. Such kits may comprise a carrier or receptacle being compartmentalized to receive and hold therein any number of containers. Such containers may contain any number of components for carrying out the methods of the invention or combinations of such components. In particular, a kit of the invention may comprise one or more components (or combinations thereof) selected from the group consisting of one or more recombination proteins or recombinases, one or more Vector Donor molecules, one or more Insert Donor molecules and one or more host cells (e.g. 20 competent cells).

25 Kits for making the Insert Donor molecules of the invention may comprise any or a number of components and the composition of such kits may vary depending on the specific method involved. Kits for synthesizing Insert Donor molecules by amplification may comprise one or more components (or combinations thereof) selected from the group consisting of one or more polypeptides having polymerase activity (preferably DNA polymerases and most preferably thermostable DNA polymerases), one or more nucleotides, and one or more primers comprising one or more recombination sites. Kits for inserting or 30 adding recombination sites to nucleic acid molecules of interest may comprise one or more nucleases (preferably restriction endonucleases), one or more ligases, one or more topoisomerases one or more polymerases, and one or more nucleic acid

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molecules or adapters comprising one or more recombination sites. Kits for integrating recombination sites into one or more nucleic acid molecules of interest may comprise one or more components (or combinations thereof) selected from the group consisting of one or more integration sequences comprising one or more recombination sites. Such integration sequences may comprise one or more transposons, integrating viruses, homologous recombination sequences, one or more host cells and the like.

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The invention also relates to compositions for carrying out the methods of the invention or compositions which are produced from carrying out the methods of the invention. In particular, such compositions may comprise one or more Insert Donor molecules, one or more Vector Donor molecules and one or more recombination proteins (or combinations thereof). In a further aspect, the compositions of the invention may comprise one or more cointegrate molecules, one or more Product molecules and one or more Byproduct molecule (or combinations thereof).

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Compositions related to preparing Insert Donor molecules may vary depending on the particular method utilized in preparing the desired Insert Donor molecules. Compositions for preparing such molecules by amplification may comprise one or more polypeptides having polymerase activity, one or more primers comprising one or more recombination sites, one or more nucleotides and one or more nucleic acid molecule to be amplified (or combinations thereof). Compositions related to inserting or adding recombination sites in a desired nucleic acid molecule may comprise one or more nucleic acid molecules or adapters comprising one or more recombination sites, one or more ligases, one or more restriction endonucleases, one or more topoisomerases, and one or more nucleic acid molecules desired to contain such recombination sites (or combinations thereof). Compositions related to integration of recombination sites in a desired nucleic acid molecule may comprise one or more integration sequences comprising one or more recombination sites and one or more nucleic acid molecules desired to contain the recombination sites.

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In a particularly preferred aspect of the invention, libraries (e.g. populations of genomic DNA or cDNA, or populations of nucleic acid molecules,

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produced by *de novo* synthesis such as random sequences or degenerate oligonucleotides) are utilized in accordance with the present invention. By inserting or adding recombination sites to such populations of nucleic acid molecules, a population of Insert Donor molecules are produced. By the recombination methods of the invention, the library may be easily moved into different vectors (or combinations of vectors) and thus into different host systems (prokaryotic and eukaryotic) to evaluate and analyze the library or a particular sequences or clones derived from the library. Alternatively, the vectors containing the desired molecule may be used *in vitro* systems such as *in vitro* expression systems for production of RNA and/or protein. In a particularly preferred aspect, one or more recombination sites are added to nucleic acid molecules of the library by method comprising:

- (a) mixing a population of linear nucleic acid molecules with one or more adapters comprising one or more recombination sites; and
- (b) incubating said mixture under conditions sufficient to add one or more of said adapters to one or more termini of said linear molecules. In a preferred aspect, the population of nucleic acid molecules are double stranded DNA molecules (preferably genomic DNA or cDNA). A population of linear fragments for use in the invention may be prepared by cleaving (by mechanical or enzymatic means) the genomic or cDNA. In a preferred aspect, the adapters are added to one or more termini of the linear molecules.

In another particularly preferred aspect of the invention, cDNA libraries are used to prepare a population of Insert Donor DNA molecules of the invention. In particular, this aspect of the invention relates to a method which comprises:

- (a) contacting a population of RNA, mRNA or polyA+ RNA templates with one or more polypeptides having reverse transcriptase activity and one or more primers which comprises one or more recombination sites;
- (b) incubating said mixture under conditions sufficient to synthesize a first population of DNA molecules complementary to said templates, wherein said DNA molecules comprise one or more recombination sites. This aspect of the invention may further comprise incubating said synthesized DNA under conditions sufficient to make a second population of DNA molecules complementary to all

or a portion of said first population of DNA molecules, thereby forming a population of double stranded DNA molecules comprising one or more recombination sites.

In a particularly preferred aspect, the Insert Donor molecules of the invention comprise at least two recombination sites and where the Insert Donor molecules are linear, such two or more recombination sites are preferably located at or near both termini of the molecules. In accordance with the invention, the use of additional recombination sites (i.e. more than two) may be used to facilitate subcloning of different inserts within the Insert Donor molecule, depending on the type and placement of such recombination sites.

Other embodiments include DNA and vectors useful in the methods of the present invention. In particular, Vector Donor molecules are provided in one embodiment, wherein DNA segments within the Vector Donor are separated either by, (i) in a circular Vector Donor, at least two recombination sites, or (ii) in a linear Vector Donor, at least one recombination site, where the recombination sites are preferably engineered to enhance specificity or efficiency of recombination. One Vector Donor embodiment comprises a first DNA segment and a second DNA segment, the first or second segment comprising a selectable marker. A second Vector Donor embodiment comprises a first DNA segment and a second DNA segment, the first or second DNA segment comprising a toxic gene. A third Vector Donor embodiment comprises a first DNA segment and a second DNA segment, the first or second DNA segment comprising an inactive fragment of at least one selectable marker, wherein the inactive fragment of the Selectable marker is capable of reconstituting a functional Selectable marker when recombined across the first or second recombination site with another inactive fragment of at least one Selectable marker.

Other preferred embodiments of the present invention will be apparent to one of ordinary skill in light of what is known in the art, in light of the following drawings and description of the invention, and in light of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts one general method of the present invention, wherein the starting (parent) DNA molecules can be circular or linear. The goal is to exchange the new subcloning vector D for the original cloning vector B. It is desirable in one embodiment to select for AD and against all the other molecules, including the Cointegrate. The square and circle are sites of recombination: *e.g.*, *loxP* sites, *att* sites, *etc.* For example, segment D can contain expression signals, new drug markers, new origins of replication, or specialized functions for mapping or sequencing DNA.

Figure 2A depicts an *in vitro* method of recombining an Insert Donor plasmid (here, pEZC705) with a Vector Donor plasmid (here, pEZC726), and obtaining Product DNA and Byproduct daughter molecules. The two recombination sites are *attP* and *loxP* on the Vector Donor. On one segment defined by these sites is a kanamycin resistance gene whose promoter has been replaced by the *tetOP* operator/promoter from transposon *Tn*10. See, e.g., Sizemore *et al.*, *Nucl. Acids Res.* 18(10):2875 (1990). In the absence of tet repressor protein, *E. coli* RNA polymerase transcribes the kanamycin resistance gene from the *tetOP*. If tet repressor is present, it binds to *tetOP* and blocks transcription of the kanamycin resistance gene. The other segment of pEZC726 has the *tet* repressor gene expressed by a constitutive promoter. Thus cells transformed by pEZC726 are resistant to chloramphenicol, because of the chloramphenicol acetyl transferase gene on the same segment as *tetR*, but are sensitive to kanamycin. The recombinase-mediated reactions result in separation of the *tetR* gene from the regulated kanamycin resistance gene. This separation results in kanamycin resistance only in cells receiving the desired recombination product. The first recombination reaction is driven by the addition of the recombinase called Integrase. The second recombination reaction is driven by adding the recombinase Cre to the Cointegrate (here, pEZC7 Cointegr).

Figure 2B depicts a restriction map of pEZC705.

Figure 2C depicts a restriction map of pEZC726.

Figure 2D depicts a restriction map of pEZC7 Coint.

Figure 2E depicts a restriction map of Intprod.

Figure 2F depicts a restriction map of Intbypro.

5 **Figure 3A** depicts an *in vitro* method of recombining an Insert Donor plasmid (here, pEYC602) with a Vector Donor plasmid (here, pEYC629), and obtaining Product (here, EZC6prod) and Byproduct (here, EZC6Bypr) daughter molecules. The two recombination sites are *loxP* and *loxP 511*. One segment of pEYC629 defined by these sites is a kanamycin resistance gene whose promoter has been replaced by the *tetOP* operator/promoter from transposon *Tn*10. In the absence of *tet* repressor protein, *E. coli* RNA polymerase transcribes the kanamycin resistance gene from the *tetOP*. If *tet* repressor is present, it binds to *tetOP* and blocks transcription of the kanamycin resistance gene. The other segment of pEYC629 has the *tet* repressor gene expressed by a constitutive promoter. Thus cells transformed by pEYC629 are resistant to chloramphenicol, because of the chloramphenicol acetyl transferase gene on the same segment as *tetR*, but are sensitive to kanamycin. The reactions result in separation of the *tetR* gene from the regulated kanamycin resistance gene. This separation results in kanamycin resistance in cells receiving the desired recombination product. The first and the second recombination events are driven by the addition of the same recombinase, Cre.

10 **Figure 3B** depicts a restriction map of EZC6Bypr.

Figure 3C depicts a restriction map of EZC6prod.

Figure 3D depicts a restriction map of pEYC602.

Figure 3E depicts a restriction map of pEYC629.

Figure 3F depicts a restriction map of EZC6coint.

15 **Figure 4A** depicts an application of the *in vitro* method of recombinational cloning to subclone the chloramphenicol acetyl transferase gene into a vector for expression in eukaryotic cells. The Insert Donor plasmid, pEYC843, is comprised of the chloramphenicol acetyl transferase gene of *E. coli*, cloned between *loxP* and *attB* sites such that the *loxP* site is positioned at the 5'-end of the gene. The Vector Donor plasmid, pEYC1003, contains the cytomegalovirus eukaryotic promoter apposed to a *loxP* site. The supercoiled plasmids were combined with

lambda Integrase and Cre recombinase *in vitro*. After incubation, competent *E. coli* cells were transformed with the recombinational reaction solution. Aliquots of transformations were spread on agar plates containing kanamycin to select for the Product molecule (here CMVProd).

5

Figure 4B depicts a restriction map of pEZC843.

Figure 4C depicts a restriction map of pEZC1003.

Figure 4D depicts a restriction map of CMVBypro.

Figure 4E depicts a restriction map of CMVProd.

Figure 4F depicts a restriction map of CMVcoint.

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Figure 5A depicts a vector diagram of pEZC1301.

Figure 5B depicts a vector diagram of pEZC1305.

Figure 5C depicts a vector diagram of pEZC1309.

Figure 5D depicts a vector diagram of pEZC1313.

Figure 5E depicts a vector diagram of pEZC1317.

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Figure 5F depicts a vector diagram of pEZC1321.

Figure 5G depicts a vector diagram of pEZC1405.

Figure 5H depicts a vector diagram of pEZC1502.

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Figure 6A depicts a vector diagram of pEZC1603.

Figure 6B depicts a vector diagram of pEZC1706.

Figure 7A depicts a vector diagram of pEZC2901.

Figure 7B depicts a vector diagram of pEZC2913.

Figure 7C depicts a vector diagram of pEZC3101.

Figure 7D depicts a vector diagram of pEZC1802.

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Figure 8A depicts a vector diagram of pGEX-2TK.

Figure 8B depicts a vector diagram of pEZC3501.

Figure 8C depicts a vector diagram of pEZC3601.

Figure 8D depicts a vector diagram of pEZC3609.

Figure 8E depicts a vector diagram of pEZC3617.

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Figure 8F depicts a vector diagram of pEZC3606.

Figure 8G depicts a vector diagram of pEZC3613.

Figure 8H depicts a vector diagram of pEZC3621.

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Figure 8I depicts a vector diagram of GST-CAT.

Figure 8J depicts a vector diagram of GST-phoA.

Figure 8K depicts a vector diagram of pEZC3201.

Figure 9A depicts a diagram of 5.2kb PCR prod.

5 **Figure 9B** depicts a vector diagram of pEZC1202.

Figure 9C depicts a vector diagram of 5.2kb clone.

Figure 10A depicts a vector diagram of pEZC5601.

Figure 10B depicts a vector diagram of pEZC6701.

Figure 10C depicts a vector diagram of attL product.

10 **Figure 10D** depicts attR product.

Figure 11A depicts a vector diagram of pEZC7102.

Figure 11B depicts a vector diagram of pEZC7501.

Figure 11C depicts the attL product.

Figure 12A depicts an amp PCR product with terminal attB sites.

15 **Figure 12B** depicts a tet PCR product with terminal attB sites.

Figure 12C depicts a restriction map of amp7102.

Figure 12D depicts a restriction map of tet 7102.

DETAILED DESCRIPTION OF THE INVENTION

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It is unexpectedly discovered in the present invention that reversible and/or repeatable cloning and subcloning reactions can be used to manipulate nucleic acids to form chimeric nucleic acids using recombination proteins and recombination sites. Recombinational cloning according to the present invention thus uses recombination proteins with recombinant nucleic acid molecules having at least one selected recombination site for moving or exchanging segments of nucleic acid molecules, *in vitro* and *in vivo*.

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These methods use recombination reactions to generate chimeric DNA or RNA molecules that have the desired characteristic(s) and/or nucleic acid segment(s). The methods of the invention provide a means in which nucleic acid molecule of interest may be moved or transferred into any number of vector systems. In accordance with the invention, such transfer to various vector systems

5 may be accomplished separately, sequentially or in mass (e.g. into any number of different vectors in one step). The improved specificity, speed and/or yields of the present invention facilitates DNA or RNA cloning, subcloning, regulation or exchange useful for any related purpose. Such purposes include *in vitro* recombination of DNA or RNA segments and *in vitro* or *in vivo* insertion or modification of transcribed, replicated, isolated or genomic DNA or RNA.

Definitions

10 In the description that follows, a number of terms used in recombinant DNA technology are utilized extensively. In order to provide a clear and consistent understanding of the specification and claims, including the scope to be given such terms, the following definitions are provided.

15 **Byproduct:** is a daughter molecule (a new clone produced after the second recombination event during the recombinational cloning process) lacking the segment which is desired to be cloned or subcloned.

20 **Cointegrate:** is at least one recombination intermediate nucleic acid molecule of the present invention that contains both parental (starting) molecules. It will usually be circular. In some embodiments it can be linear.

25 **Host:** is any prokaryotic or eukaryotic organism that can be a recipient of the recombinational cloning Product. A "host," as the term is used herein, includes prokaryotic or eukaryotic organisms that can be genetically engineered. For examples of such hosts, *see Maniatis et al., Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory, Cold Spring Harbor, New York (1982).

30 **Insert or Inserts:** include the desired nucleic acid segment or a population of nucleic acid segments (segment A of Figure 1) which may be manipulated by the methods of the present invention. Thus, the terms Insert(s) are meant to include a particular nucleic acid (preferably DNA) segment or a population of segments. Such Insert(s) can comprise one or more genes.

Insert Donor: is one of the two parental nucleic acid molecules (e.g. RNA or DNA) of the present invention which carries the Insert. The Insert Donor molecule comprises the Insert flanked on both sides with recombination sites.

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The Insert Donor can be linear or circular. In one embodiment of the invention, the Insert Donor is a circular DNA molecule and further comprises a cloning vector sequence outside of the recombination signals (see Figure 1). When a population of Inserts or population of nucleic acid segments are used to make the Insert Donor, a population of Insert Donors result and may be used in accordance with the invention.

10

Product: is one the desired daughter molecules comprising the *A* and *D* sequences which is produced after the second recombination event during the recombinational cloning process (see Figure 1). The Product contains the nucleic acid which was to be cloned or subcloned. In accordance with the invention, when a population of Insert Donors are used, the resulting population of Product molecules will contain all or a portion of the population of Inserts of the Insert Donors and preferably will contain a representative population of the original molecules of the Insert Donors.

15

Promoter: is a DNA sequence generally described as the 5'-region of a gene, located proximal to the start codon. The transcription of an adjacent DNA segment is initiated at the promoter region. A repressible promoter's rate of transcription decreases in response to a repressing agent. An inducible promoter's rate of transcription increases in response to an inducing agent. A constitutive promoter's rate of transcription is not specifically regulated, though it can vary under the influence of general metabolic conditions.

20

Recognition sequence: Recognition sequences are particular sequences which a protein, chemical compound, DNA, or RNA molecule (e.g., restriction endonuclease, a modification methylase, or a recombinase) recognizes and binds. In the present invention, a recognition sequence will usually refer to a recombination site. For example, the recognition sequence for Cre recombinase is *loxP* which is a 34 base pair sequence comprised of two 13 base pair inverted repeats (serving as the recombinase binding sites) flanking an 8 base pair core sequence. *See Figure 1 of Sauer, B., Current Opinion in Biotechnology 5:521-527 (1994).* Other examples of recognition sequences are the *attB*, *attP*, *attL*, and *attR* sequences which are recognized by the recombinase enzyme

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5 λ Integrase. *attB* is an approximately 25 base pair sequence containing two 9 base pair core-type Int binding sites and a 7 base pair overlap region. *attP* is an approximately 240 base pair sequence containing core-type Int binding sites and arm-type Int binding sites as well as sites for auxiliary proteins integration host factor (IHF), FIS and excisionase (Xis). See Landy, *Current Opinion in Biotechnology* 3:699-707 (1993). Such sites may also be engineered according to the present invention to enhance production of products in the methods of the invention. When such engineered sites lack the P1 or H1 domains to make the recombination reactions irreversible (e.g., *attR* or *attP*), such sites may be designated *attR'* or *attP'* to show that the domains of these sites have been modified in some way.

10

Recombinase: is an enzyme which catalyzes the exchange of DNA segments at specific recombination sites.

15 **Recombinational Cloning:** is a method described herein, whereby segments of nucleic acid molecules or populations of such molecules are exchanged, inserted, replaced, substituted or modified, *in vitro* or *in vivo*.

20 **Recombination proteins:** include excisive or integrative proteins, enzymes, co-factors or associated proteins that are involved in recombination reactions involving one or more recombination sites. See, Landy (1994), *infra*.

25 **Repression cassette:** is a nucleic acid segment that contains a repressor of a Selectable marker present in the subcloning vector.

30 **Selectable marker:** is a DNA segment that allows one to select for or against a molecule or a cell that contains it, often under particular conditions. These markers can encode an activity, such as, but not limited to, production of RNA, peptide, or protein, or can provide a binding site for RNA, peptides, proteins, inorganic and organic compounds or compositions and the like. Examples of Selectable markers include but are not limited to: (1) DNA segments that encode products which provide resistance against otherwise toxic compounds (e.g., antibiotics); (2) DNA segments that encode products which are otherwise lacking in the recipient cell (e.g., tRNA genes, auxotrophic markers); (3) DNA segments that encode products which suppress the activity of a gene product; (4)

DNA segments that encode products which can be readily identified (e.g., phenotypic markers such as β -galactosidase, green fluorescent protein (GFP), and cell surface proteins); (5) DNA segments that bind products which are otherwise detrimental to cell survival and/or function; (6) DNA segments that otherwise inhibit the activity of any of the DNA segments described in Nos. 1-5 above (e.g., antisense oligonucleotides); (7) DNA segments that bind products that modify a substrate (e.g. restriction endonucleases); (8) DNA segments that can be used to isolate or identify a desired molecule (e.g. specific protein binding sites); (9) DNA segments that encode a specific nucleotide sequence which can be otherwise non-functional (e.g., for PCR amplification of subpopulations of molecules); (10) DNA segments, which when absent, directly or indirectly confer resistance or sensitivity to particular compounds; and/or (11) DNA segments that encode products which are toxic in recipient cells.

Selection scheme: is any method which allows selection, enrichment, or identification of a desired Product or Product(s) from a mixture containing the Insert Donor, Vector Donor, any intermediates (e.g. a Cointegrate), and/or Byproducts. The selection schemes of one preferred embodiment have at least two components that are either linked or unlinked during recombinational cloning. One component is a Selectable marker. The other component controls the expression *in vitro* or *in vivo* of the Selectable marker, or survival of the cell harboring the plasmid carrying the Selectable marker. Generally, this controlling element will be a repressor or inducer of the Selectable marker, but other means for controlling expression of the Selectable marker can be used. Whether a repressor or activator is used will depend on whether the marker is for a positive or negative selection, and the exact arrangement of the various DNA segments, as will be readily apparent to those skilled in the art. A preferred requirement is that the selection scheme results in selection of or enrichment for only one or more desired Products. As defined herein, selecting for a DNA molecule includes (a) selecting or enriching for the presence of the desired DNA molecule, and (b) selecting or enriching against the presence of DNA molecules that are not the desired DNA molecule.

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In one embodiment, the selection schemes (which can be carried out in reverse) will take one of three forms, which will be discussed in terms of Figure 1. The first, exemplified herein with a Selectable marker and a repressor therefore, selects for molecules having segment *D* and lacking segment *C*. The second selects against molecules having segment *C* and for molecules having segment *D*. Possible embodiments of the second form would have a DNA segment carrying a gene toxic to cells into which the *in vitro* reaction products are to be introduced. A toxic gene can be a DNA that is expressed as a toxic gene product (a toxic protein or RNA), or can be toxic in and of itself. (In the latter case, the toxic gene is understood to carry its classical definition of "heritable trait".)

Examples of such toxic gene products are well known in the art, and include, but are not limited to, restriction endonucleases (e.g., *Dpn*I), apoptosis-related genes (e.g. ASK1 or members of the bcl-2/ced-9 family), retroviral genes including those of the human immunodeficiency virus (HIV), defensins such as NP-1, inverted repeats or paired palindromic DNA sequences, bacteriophage lytic genes such as those from ϕ X174 or bacteriophage T4; antibiotic sensitivity genes such as *rpsL*, antimicrobial sensitivity genes such as *pheS*, plasmid killer genes, eukaryotic transcriptional vector genes that produce a gene product toxic to bacteria, such as GATA-1, and genes that kill hosts in the absence of a suppressing function, e.g., *kicB* or *ccdB*. A toxic gene can alternatively be selectable *in vitro*, e.g., a restriction site.

Many genes coding for restriction endonucleases operably linked to inducible promoters are known, and may be used in the present invention. See, e.g. U.S. Patent Nos. 4,960,707 (*Dpn*I and *Dpn*II); 5,000,333, 5,082,784 and 5,192,675 (*Kpn*I); 5,147,800 (*Ngo*AIII and *Ngo*AI); 5,179,015 (*Fsp*I and *Hae*III); 5,200,333 (*Hae*II and *Taq*I); 5,248,605 (*Hpa*II); 5,312,746 (*Clal*); 5,231,021 and 5,304,480 (*Xho*I and *Xho*II); 5,334,526 (*Ahu*I); 5,470,740 (*Nsi*I); 5,534,428 (*Sst*I/*Sac*I); 5,202,248 (*Nco*I); 5,139,942 (*Nde*I); and 5,098,839 (*Pac*I). See also Wilson, G.G., *Nucl. Acids Res.* 19:2539-2566 (1991); and Lunnen, K.D., *et al.*, *Gene* 74:25-32 (1988).

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In the second form, segment **D** carries a Selectable marker. The toxic gene would eliminate transformants harboring the Vector Donor, Cointegrate, and Byproduct molecules, while the Selectable marker can be used to select for cells containing the Product and against cells harboring only the Insert Donor.

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The third form selects for cells that have both segments **A** and **D** in *cis* on the same molecule, but not for cells that have both segments in *trans* on different molecules. This could be embodied by a Selectable marker that is split into two inactive fragments, one each on segments **A** and **D**.

10

The fragments are so arranged relative to the recombination sites that when the segments are brought together by the recombination event, they reconstitute a functional Selectable marker. For example, the recombinational event can link a promoter with a structural gene, can link two fragments of a structural gene, or can link genes that encode a heterodimeric gene product needed for survival, or can link portions of a replicon.

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Site-specific recombinase: is a type of recombinase which typically has at least the following four activities (or combinations thereof): (1) recognition of one or two specific nucleic acid sequences; (2) cleavage of said sequence or sequences; (3) topoisomerase activity involved in strand exchange; and (4) ligase activity to reseal the cleaved strands of nucleic acid. *See* Sauer, B., *Current Opinions in Biotechnology* 5:521-527 (1994). Conservative site-specific recombination is distinguished from homologous recombination and transposition by a high degree of specificity for both partners. The strand exchange mechanism involves the cleavage and rejoining of specific DNA sequences in the absence of DNA synthesis (Landy, A. (1989) *Ann. Rev. Biochem.* 58:913-949).

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Subcloning vector: is a cloning vector comprising a circular or linear nucleic acid molecule which includes preferably an appropriate replicon. In the present invention, the subcloning vector (segment **D** in Figure 1) can also contain functional and/or regulatory elements that are desired to be incorporated into the final product to act upon or with the cloned DNA Insert (segment **A** in Figure 1). The subcloning vector can also contain a Selectable marker (preferably DNA).

5 **Vector:** is a nucleic acid molecule (preferably DNA) that provides a useful biological or biochemical property to an Insert. Examples include plasmids, phages, autonomously replicating sequences (ARS), centromeres, and other sequences which are able to replicate or be replicated *in vitro* or in a host cell, or to convey a desired nucleic acid segment to a desired location within a host cell.

10 A Vector can have one or more restriction endonuclease recognition sites at which the sequences can be cut in a determinable fashion without loss of an essential biological function of the vector, and into which a nucleic acid fragment can be spliced in order to bring about its replication and cloning. Vectors can further provide primer sites, *e.g.*, for PCR, transcriptional and/or translational initiation and/or regulation sites, recombinational signals, replicons, Selectable markers, *etc.* Clearly, methods of inserting a desired nucleic acid fragment which do not require the use of homologous recombination, transpositions or restriction enzymes (such as, but not limited to, UDG cloning of PCR fragments (U.S. Patent No. 5,334,575, entirely incorporated herein by reference), T:A cloning, and the like) can also be applied to clone a fragment into a cloning vector to be used according to the present invention. The cloning vector can further contain one or more selectable markers suitable for use in the identification of cells transformed with the cloning vector.

15

20 **Vector Donor:** is one of the two parental nucleic acid molecules (*e.g.* RNA or DNA) of the present invention which carries the DNA segments comprising the DNA vector which is to become part of the desired Product. The Vector Donor comprises a subcloning vector **D** (or it can be called the cloning vector if the Insert Donor does not already contain a cloning vector) and a segment **C** flanked by recombination sites (see Figure 1). Segments **C** and/or **D** can contain elements that contribute to selection for the desired Product daughter molecule, as described above for selection schemes. The recombination signals can be the same or different, and can be acted upon by the same or different recombinases. In addition, the Vector Donor can be linear or circular.

25

30 **Primer:** refers to a single stranded or double stranded oligonucleotide that is extended by covalent bonding of nucleotide monomers during amplification or

polymerization of a nucleic acid molecule (e.g. a DNA molecule). In a preferred aspect, the primer comprises one or more recombination sites or portions of such recombination sites. Portions of recombination sites comprise at least 2 bases, at least 5 bases, at least 10 bases or at least 20 bases of the recombination sites of interest. When using portions of recombination sites, the missing portion of the recombination site may be provided by the newly synthesized nucleic acid molecule. Such recombination sites may be located within and/or at one or both termini of the primer. Preferably, additional sequences are added to the primer adjacent to the recombination site(s) to enhance or improve recombination and/or to stabilize the recombination site during recombination. Such stabilization sequences may be any sequences (preferably G/C rich sequences) of any length. Preferably, such sequences range in size from 1 to about 1000 bases, 1 to about 500 bases, and 1 to about 100 bases, 1 to about 60 bases, 1 to about 25, 1 to about 10, 2 to about 10 and preferably about 4 bases. Preferably, such sequences are greater than 1 base in length and preferably greater than 2 bases in length.

Template: refers to double stranded or single stranded nucleic acid molecules which are to be amplified, synthesized or sequenced. In the case of double stranded molecules, denaturation of its strands to form a first and a second strand is preferably performed before these molecules will be amplified, synthesized or sequenced, or the double stranded molecule may be used directly as a template. For single stranded templates, a primer complementary to a portion of the template is hybridized under appropriate conditions and one or more polypeptides having polymerase activity (e.g. DNA polymerases and/or reverse transcriptases) may then synthesize a nucleic acid molecule complementary to all or a portion of said template. Alternatively, for double stranded templates, one or more promoters may be used in combination with one or more polymerases to make nucleic acid molecules complementary to all or a portion of the template. The newly synthesized molecules, according to the invention, may be equal or shorter in length than the original template. Additionally, a population of nucleic acid templates may be used during synthesis or amplification to produce a population of nucleic acid molecules typically representative of the original template population.

Adapter: is an oligonucleotide or nucleic acid fragment or segment (preferably DNA) which comprises one or more recombination sites (or portions of such recombination sites) which in accordance with the invention can be added to a circular or linear Insert Donor molecule as well as other nucleic acid molecules described herein. When using portions of recombination sites, the missing portion may be provided by the Insert Donor molecule. Such adapters may be added at any location within a circular or linear molecule, although the adapters are preferably added at or near one or both termini of a linear molecule. Preferably, adapters are positioned to be located on both sides (flanking) a particularly nucleic acid molecule of interest. In accordance with the invention, adapters may be added to nucleic acid molecules of interest by standard recombinant techniques (e.g. restriction digest and ligation). For example, adapters may be added to a circular molecule by first digesting the molecule with an appropriate restriction enzyme, adding the adapter at the cleavage site and reforming the circular molecule which contains the adapter(s) at the site of cleavage. Alternatively, adapters may be ligated directly to one or more and preferably both termini of a linear molecule thereby resulting in linear molecule(s) having adapters at one or both termini. In one aspect of the invention, adapters may be added to a population of linear molecules, (e.g. a cDNA library or genomic DNA which has been cleaved or digested) to form a population of linear molecules containing adapters at one and preferably both termini of all or substantial portion of said population.

Amplification: refers to any *in vitro* method for increasing a number of copies of a nucleotide sequence with the use of a polymerase. Nucleic acid amplification results in the incorporation of nucleotides into a DNA and/or RNA molecule or primer thereby forming a new molecule complementary to a template. The formed nucleic acid molecule and its template can be used as templates to synthesize additional nucleic acid molecules. As used herein, one amplification reaction may consist of many rounds of replication. DNA amplification reactions include, for example, polymerase chain reaction (PCR). One PCR reaction may consist of 5-100 "cycles" of denaturation and synthesis of a DNA molecule.

Oligonucleotide: refers to a synthetic or natural molecule comprising a covalently linked sequence of nucleotides which are joined by a phosphodiester bond between the 3' position of the deoxyribose or ribose of one nucleotide and the 5' position of the deoxyribose or ribose of the adjacent nucleotide.

Nucleotide: refers to a base-sugar-phosphate combination. Nucleotides are monomeric units of a nucleic acid sequence (DNA and RNA). The term nucleotide includes ribonucleoside triphosphatase ATP, UTP, CTG, GTP and deoxyribonucleoside triphosphates such as dATP, dCTP, dITP, dUTP, dGTP, dTTP, or derivatives thereof. Such derivatives include, for example, [α S]dATP, 7-deaza-dGTP and 7-deaza-dATP. The term nucleotide as used herein also refers to dideoxyribonucleoside triphosphates (ddNTPs) and their derivatives. Illustrated examples of dideoxyribonucleoside triphosphates include, but are not limited to, ddATP, ddCTP, ddGTP, ddITP, and ddTTP. According to the present invention, a "nucleotide" may be unlabeled or detectably labeled by well known techniques. Detectable labels include, for example, radioactive isotopes, fluorescent labels, chemiluminescent labels, bioluminescent labels and enzyme labels.

Hybridization: The terms "hybridization" and "hybridizing" refers to base pairing of two complementary single-stranded nucleic acid molecules (RNA and/or DNA) to give a double stranded molecule. As used herein, two nucleic acid molecules may be hybridized, although the base pairing is not completely complementary. Accordingly, mismatched bases do not prevent hybridization of

two nucleic acid molecules provided that appropriate conditions, well known in the art, are used.

Other terms used in the fields of recombinant DNA technology and molecular and cell biology as used herein will be generally understood by one of ordinary skill in the applicable arts.

Recombination Schemes

One general scheme for an *in vitro* or *in vivo* method of the invention is shown in Figure 1, where the Insert Donor and the Vector Donor can be either circular or linear DNA, but is shown as circular. Vector *D* is exchanged for the original cloning vector *B*. The Insert Donor need not comprise a vector. The method of the invention allows the Inserts *A* to be transferred into any number of vectors. According to the invention, the Inserts may be transferred to a particular Vector or may be transferred to a number of vectors in one step. Additionally, the Inserts may be transferred to any number of vectors sequentially, for example, by using the Product DNA molecule as the Insert Donor in combination with a different Vector Donor. The nucleic acid molecule of interest may be transferred into a new vector thereby producing a new Product DNA molecule. The new Product DNA molecule may then be used as starting material to transfer the nucleic acid molecule of interest into a new vector. Such sequential transfers can be performed a number of times in any number of different vectors. Thus the invention allows for cloning or subcloning nucleic acid molecules and because of the ease and simplicity, these methods are particularly suited for high through-put applications. In accordance with the invention, it is desirable to select for the daughter molecule containing elements *A* and *D* and against other molecules, including one or more Cointegrate(s). The square and circle are different sets of recombination sites (e.g., *lox* sites or *att* sites). Segment *A* or *D* can contain at least one Selection Marker, expression signals, origins of replication, or specialized functions for detecting, selecting, expressing, mapping or sequencing DNA, where *D* is used in this example. This scheme can also be reversed according to the present invention, as described herein. The resulting product of

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the reverse reaction (e.g. the Insert Donor) may then be used in combination with one or a number of vectors to produce new product molecules in which the Inserts are contained by any number of vectors.

Examples of desired DNA segments that can be part of Element *A* or *D* include, but are not limited to, PCR products, large DNA segments, genomic clones or fragments, cDNA clones or fragments, functional elements, *etc.*, and genes or partial genes, which encode useful nucleic acids or proteins. Moreover, the recombinational cloning of the present invention can be used to make *ex vivo* and *in vivo* gene transfer vehicles for protein expression (native or fusion proteins) and/or gene therapy.

In Figure 1, the scheme provides the desired Product as containing *A* and Vector *D*, as follows. The Insert Donor (containing *A* and *B*) is first recombined at the square recombination sites by recombination proteins, with the Vector Donor (containing *C* and *D*), to form a Co-integrate having each of A-D-C-B. Next, recombination occurs at the circle recombination sites to form Product DNA (*A* and *D*) and Byproduct DNA (*C* and *B*). However, if desired, two or more different Co-integrates can be formed to generate two or more Products.

In one embodiment of the present *in vitro* or *in vivo* recombinational cloning method, a method for selecting at least one desired Product DNA is provided. This can be understood by consideration of the map of plasmid pEYC726 depicted in Figure 2. The two exemplary recombination sites are *attP* and *loxP*. On one segment defined by these sites is a kanamycin resistance gene whose promoter has been replaced by the *tetOP* operator/promoter from transposon *Tn*10. In the absence of tet repressor protein, *E. coli* RNA polymerase transcribes the kanamycin resistance gene from the *tetOP*. If tet repressor is present, it binds to *tetOP* and blocks transcription of the kanamycin resistance gene. The other segment of pEYC726 has the *tet* repressor gene expressed by a constitutive promoter. Thus cells transformed by pEYC726 are resistant to chloramphenicol, because of the chloramphenicol acetyl transferase gene on the same segment as *tetR*, but are sensitive to kanamycin. The recombination reactions result in separation of the *tetR* gene from the regulated kanamycin

resistance gene. This separation results in kanamycin resistance in cells receiving the desired recombination Product.

Two different sets of plasmids were constructed to demonstrate the *in vitro* method. One set, for use with Cre recombinase only (cloning vector 602 and subcloning vector 629 (Figure 3)) contained *loxP* and *loxP 511* sites. A second set, for use with Cre and integrase (cloning vector 705 and subcloning vector 726 (Figure 2)) contained *loxP* and *att* sites. The efficiency of production of the desired daughter plasmid was about 60 fold higher using both enzymes than using Cre alone. Nineteen of twenty four colonies from the Cre-only reaction contained the desired product, while thirty eight of thirty eight colonies from the integrase plus Cre reaction contained the desired product plasmid.

A variety of other selection schemes can be used that are known in the art as they can suit a particular purpose for which the recombinational cloning is carried out. Depending upon individual preferences and needs, a number of different types of selection schemes can be used in the recombinational cloning or subcloning methods of the present invention. The skilled artisan can take advantage of the availability of the many DNA segments or methods for making them and the different methods of selection that are routinely used in the art. Such DNA segments include but are not limited to those which encodes an activity such as, but not limited to, production of RNA, peptide, or protein, or providing a binding site for such RNA, peptide, or protein. Examples of DNA molecules used in devising a selection scheme are given above, under the definition of "selection scheme"

Additional examples include but are not limited to:

- (i) Generation of new primer sites for PCR (*e.g.*, juxtaposition of two DNA sequences that were not previously juxtaposed);
- (ii) Inclusion of a DNA sequence acted upon by a restriction endonuclease or other DNA modifying enzyme, chemical, ribozyme, etc.;
- (iii) Inclusion of a DNA sequence recognized by a DNA binding protein, RNA, DNA, chemical, etc.) (*e.g.*, for use as an affinity tag for selecting for or excluding from a population (Davis, *Nucl.*

Acids Res. 24:702-706 (1996); *J. Virol.* 69: 8027-8034 (1995))

or for juxtaposing a promoter for *in vitro* transcription;

5 (iv) *In vitro* selection of RNA ligands for the ribosomal L22 protein associated with Epstein-Barr virus-expressed RNA by using randomized and cDNA-derived RNA libraries;

10 (vi) The positioning of functional elements whose activity requires a specific orientation or juxtaposition (e.g., (a) a recombination site which reacts poorly in *trans*, but when placed in *cis*, in the presence of the appropriate proteins, results in recombination that destroys certain populations of molecules; (e.g., reconstitution of a promoter sequence that allows *in vitro* RNA synthesis). The RNA can be used directly, or can be reverse transcribed to obtain the desired DNA construct;

15 (vii) Selection of the desired product by size (e.g., fractionation) or other physical property of the molecule(s); and

20 (viii) Inclusion of a DNA sequence required for a specific modification (e.g., methylation) that allows its identification.

25 After formation of the Product and Byproduct in the method of the present invention, the selection step can be carried out either *in vitro* or *in vivo* depending upon the particular selection scheme which has been optionally devised in the particular recombinational cloning procedure.

30 For example, an *in vitro* method of selection can be devised for the Insert Donor and Vector-Donor DNA molecules. Such scheme can involve engineering a rare restriction site in the starting circular vectors in such a way that after the recombination events the rare cutting sites end up in the Byproduct. Hence, when the restriction enzyme which binds and cuts at the rare restriction site is added to the reaction mixture *in vitro*, all of the DNA molecules carrying the rare cutting site, *i.e.*, the starting DNA molecules, the Cointegrate, and the Byproduct, will be cut and rendered nonreplicable in the intended host cell. For example, cutting sites in segments *B* and *C* (see Figure 1) can be used to select against all molecules

except the Product. Alternatively, only a cutting site in **C** is needed if one is able to select for segment **D**, *e.g.*, by a drug resistance gene not found on **B**.

Similarly, an *in vitro* selection method can be devised when dealing with linear DNA molecules. DNA sequences complementary to a PCR primer sequence can be so engineered that they are transferred, through the recombinational cloning method, only to the Product molecule. After the reactions are completed, the appropriate primers are added to the reaction solution and the sample is subjected to PCR. Hence, all or part of the Product molecule is amplified.

Other *in vivo* selection schemes can be used with a variety of host cells, particularly *E. coli* lines. One is to put a repressor gene on one segment of the subcloning plasmid, and a drug marker controlled by that repressor on the other segment of the same plasmid. Another is to put a killer gene on segment **C** of the subcloning plasmid (Figure 1). Of course a way must exist for growing such a plasmid, *i.e.*, there must exist circumstances under which the killer gene will not kill. There are a number of these genes known which require particular strains of *E. coli*. One such scheme is to use the restriction enzyme *Dpn*I, which will not cleave unless its recognition sequence GATC is methylated. Many popular common *E. coli* strains methylate GATC sequences, but there are mutants in which cloned *Dpn*I can be expressed without harm. Other restriction enzyme genes may also be used as a toxic gene for selection. In such cases, a host containing a gene encoding the corresponding methylase gene provides protected host for use in the invention. Similarly, the *ccdB* protein is a potent poison of DNA gyrase, efficiently trapping gyrase molecules in a cleavable complex, resulting in DNA strand breakage and cell death. Mutations in the *gyrA* subunit of DNA gyrase, specifically the *gyrA462* mutation, confers resistance to *ccdB* (Bernard and Couturier, *J. Mol. Bio.* 226 (1992) 735-745). An *E. coli* strain, DB2, has been constructed that contains the *gyrA462* mutation. DB2 cells containing plasmids that express the *ccdB* gene are not killed by *ccdB*. This strain is available from Life Technologies and has been deposited on October 14, 1997 with the Collection, Agricultural Research Culture Collection (NRRL), 1815

North University Street, Peoria, IL 61604 USA as deposit number NRRL B-21852.

Of course analogous selection schemes can be devised for other host organisms. For example, the *tet* repressor/operator of *Tn10* has been adapted to control gene expression in eukaryotes (Gossen, M., and Bujard, H., *Proc. Natl. Acad. Sci. USA* 89:5547-5551 (1992)). Thus the same control of drug resistance by the *tet* repressor exemplified herein or other selection schemes described herein can be applied to select for Product in eukaryotic cells.

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Recombination Proteins

In the present invention, the exchange of DNA segments is achieved by the use of recombination proteins, including recombinases and associated co-factors and proteins. Various recombination proteins are described in the art. Examples of such recombinases include:

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Cre: A protein from bacteriophage P1 (Abremski and Hoess, *J. Biol. Chem.* 259(3):1509-1514 (1984)) catalyzes the exchange (i.e., causes recombination) between 34 bp DNA sequences called *loxP* (locus of crossover) sites (See Hoess *et al.*, *Nucl. Acids Res.* 14(5):2287 (1986)). *Cre* is available commercially (Novagen, Catalog No. 69247-1). Recombination mediated by *Cre* is freely reversible. From thermodynamic considerations it is not surprising that *Cre*-mediated integration (recombination between two molecules to form one molecule) is much less efficient than *Cre*-mediated excision (recombination between two *loxP* sites in the same molecule to form two daughter molecules). *Cre* works in simple buffers with either magnesium or spermidine as a cofactor, as is well known in the art. The DNA substrates can be either linear or supercoiled. A number of mutant *loxP* sites have been described (Hoess *et al.*, *supra*). One of these, *loxP* 511, recombines with another *loxP* 511 site, but will not recombine with a *loxP* site.

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Integrase: A protein from bacteriophage lambda that mediates the integration of the lambda genome into the *E. coli* chromosome. The bacteriophage λ Int recombinational proteins promote recombination between its substrate *att* sites as part of the formation or induction of a lysogenic state.

5 Reversibility of the recombination reactions results from two independent pathways for integrative and excisive recombination. Each pathway uses a unique, but overlapping, set of the 15 protein binding sites that comprise *att* site DNAs. Cooperative and competitive interactions involving four proteins (Int, Xis, IHF and FIS) determine the direction of recombination.

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Integrative recombination involves the Int and IHF proteins and sites *attP* (240 bp) and *attB* (25 bp). Recombination results in the formation of two new sites: *attL* and *attR*. Excisive recombination requires Int, IHF, and Xis, and sites *attL* and *attR* to generate *attP* and *attB*. Under certain conditions, FIS stimulates excisive recombination. In addition to these normal reactions, it should be appreciated that *attP* and *attB*, when placed on the same molecule, can promote *excisive* recombination to generate two excision products, one with *attL* and one with *attR*. Similarly, intermolecular recombination between molecules containing *attL* and *attR*, in the presence of Int, IHF and Xis, can result in *integrative* recombination and the generation of *attP* and *attB*. Hence, by flanking DNA segments with appropriate combinations of engineered *att* sites, in the presence of the appropriate recombination proteins, one can direct excisive or integrative recombination, as reverse reactions of each other.

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Each of the *att* sites contains a 15 bp core sequence; individual sequence elements of functional significance lie within, outside, and across the boundaries of this common core (Landy, A., *Ann. Rev. Biochem.* 58:913 (1989)). Efficient recombination between the various *att* sites requires that the sequence of the central common region be identical between the recombining partners, however, the exact sequence is now found to be modifiable. Consequently, derivatives of the *att* site with changes within the core are now discovered to recombine as least as efficiently as the native core sequences.

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Integrase acts to recombine the *attP* site on bacteriophage lambda (about 240 bp) with the *attB* site on the *E. coli* genome (about 25 bp) (Weisberg, R.A. and Landy, A. in *Lambda II*, p. 211 (1983), Cold Spring Harbor Laboratory), to produce the integrated lambda genome flanked by *attL* (about 100 bp) and *attR* (about 160 bp) sites. In the absence of Xis (see below), this reaction is essentially irreversible. The integration reaction mediated by integrase and IHF works

in vitro, with simple buffer containing spermidine. Integrase can be obtained as described by Nash, H.A., *Methods of Enzymology* 100:210-216 (1983). IHF can be obtained as described by Filutowicz, M., *et al.*, *Gene* 147:149-150 (1994).

5 Numerous recombination systems from various organisms can also be used, based on the teaching and guidance provided herein. See, e.g., Hoess *et al.*, *Nucleic Acids Research* 14(6):2287 (1986); Abremski *et al.*, *J. Biol. Chem.* 261(1):391 (1986); Campbell, *J. Bacteriol.* 174(23):7495 (1992); Qian *et al.*, *J. Biol. Chem.* 267(11):7794 (1992); Araki *et al.*, *J. Mol. Biol.* 225(1):25 (1992)). Many of these belong to the integrase family of recombinases (Argos *et al.* *EMBO J.* 5:433-440 (1986)). Perhaps the best studied of these are the Integrase/att system from bacteriophage λ (Landy, A. (1993) *Current Opinions in Genetics and Devel.* 3:699-707), the Cre/loxP system from bacteriophage P1 (Hoess and Abremski (1990) In *Nucleic Acids and Molecular Biology*, vol. 4. Eds.: Eckstein and Lilley, Berlin-Heidelberg: Springer-Verlag; pp. 90-109), and the FLP/FRT system from the *Saccharomyces cerevisiae* 2 μ circle plasmid (Broach *et al.* *Cell* 29:227-234 (1982)).

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20 Members of a second family of site-specific recombinases, the resolvase family (e.g., $\gamma\delta$, Tn3 resolvase, Hin, Gin, and Cin) are also known. Members of this highly related family of recombinases are typically constrained to intramolecular reactions (e.g., inversions and excisions) and can require host-encoded factors. Mutants have been isolated that relieve some of the requirements for host factors (Maeser and Kahnmann (1991) *Mol. Gen. Genet.* 230:170-176), as well as some of the constraints of intramolecular recombination.

25 Other site-specific recombinases similar to λ Int and similar to P1 Cre can be substituted for Int and Cre. Such recombinases are known. In many cases the purification of such other recombinases has been described in the art. In cases when they are not known, cell extracts can be used or the enzymes can be partially purified using procedures described for Cre and Int.

30 While Cre and Int are described in detail for reasons of example, many related recombinase systems exist and their application to the described invention is also provided according to the present invention. The integrase family of site-specific recombinases can be used to provide alternative recombination proteins

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and recombination sites for the present invention, as site-specific recombination proteins encoded by, for example bacteriophage lambda, phi 80, P22, P2, 186, P4 and P1. This group of proteins exhibits an unexpectedly large diversity of sequences. Despite this diversity, all of the recombinases can be aligned in their C-terminal halves. A 40-residue region near the C terminus is particularly well conserved in all the proteins and is homologous to a region near the C terminus of the yeast 2 mu plasmid Flp protein. Three positions are perfectly conserved within this family: histidine, arginine and tyrosine are found at respective alignment positions 396, 399 and 433 within the well-conserved C-terminal region. These residues contribute to the active site of this family of recombinases, and suggest that tyrosine-433 forms a transient covalent linkage to DNA during strand cleavage and rejoining. *See, e.g., Argos, P. et al., EMBO J. 5:433-40 (1986).*

The recombinases of some transposons, such as those of conjugative transposons (e.g., Tn916) (Scott and Churchward. 1995. Ann Rev Microbiol 49:367; Taylor and Churchward, 1997. J Bacteriol 179:1837) belong to the integrase family of recombinases and in some cases show strong preferences for specific integration sites (Ike et al 1992. J Bacteriol 174:1801; Trieu-Cuot et al, 1993. Mol. Microbiol 8:179).

Alternatively, IS231 and other *Bacillus thuringiensis* transposable elements could be used as recombination proteins and recombination sites. *Bacillus thuringiensis* is an entomopathogenic bacterium whose toxicity is due to the presence in the sporangia of delta-endotoxin crystals active against agricultural pests and vectors of human and animal diseases. Most of the genes coding for these toxin proteins are plasmid-borne and are generally structurally associated with insertion sequences (IS231, IS232, IS240, ISBT1 and ISBT2) and transposons (Tn4430 and Tn5401). Several of these mobile elements have been shown to be active and participate in the crystal gene mobility, thereby contributing to the variation of bacterial toxicity.

Structural analysis of the iso-IS231 elements indicates that they are related to IS1151 from *Clostridium perfringens* and distantly related to IS4 and IS186 from *Escherichia coli*. Like the other IS4 family members, they contain a conserved transposase-integrase motif found in other IS families and retroviruses.

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Moreover, functional data gathered from IS231A in *Escherichia coli* indicate a non-replicative mode of transposition, with a preference for specific targets. Similar results were also obtained in *Bacillus subtilis* and *B. thuringiensis*. See, e.g., Mahillon, J. et al., *Genetica* 93:13-26 (1994); Campbell, J. *Bacteriol.* 7495-7499 (1992).

An unrelated family of recombinases, the transposases, have also been used to transfer genetic information between replicons. Transposons are structurally variable, being described as simple or compound, but typically encode the recombinase gene flanked by DNA sequences organized in inverted orientations. Integration of transposons can be random or highly specific. Representatives such as Tn7, which are highly site-specific, have been applied to the efficient movement of DNA segments between replicons (Lucklow et al. 1993. *J. Virol.* 67:4566-4579).

A related element, the integron, are also translocatable-promoting movement of drug resistance cassettes from one replicon to another. Often these elements are defective transposon derivatives. Transposon Tn21 contains a class I integron called In2. The integrase (IntI1) from In2 is common to all integrons in this class and mediates recombination between two 59-bp elements or between a 59-bp element and an attI site that can lead to insertion into a recipient integron. The integrase also catalyzes excisive recombination. (Hall, 1997. *Ciba Found Symp* 207:192; Francia et al., 1997. *J Bacteriol* 179:4419).

Group II introns are mobile genetic elements encoding a catalytic RNA and protein. The protein component possesses reverse transcriptase, maturase and an endonuclease activity, while the RNA possesses endonuclease activity and determines the sequence of the target site into which the intron integrates. By modifying portions of the RNA sequence, the integration sites into which the element integrates can be defined. Foreign DNA sequences can be incorporated between the ends of the intron, allowing targeting to specific sites. This process, termed retrohoming, occurs via a DNA:RNA intermediate, which is copied into cDNA and ultimately into double stranded DNA (Matsuura et al., *Genes and Dev* 1997; Guo et al, *EMBO J*, 1997). Numerous intron-encoded homing endonucleases have been identified (Belfort and Roberts, 1997. *NAR*

25:3379). Such systems can be easily adopted for application to the described subcloning methods.

5 The amount of recombinase which is added to drive the recombination reaction can be determined by using known assays. Specifically, titration assay is used to determine the appropriate amount of a purified recombinase enzyme, or the appropriate amount of an extract.

Engineered Recombination Sites

10 The above recombinases and corresponding recombinase sites are suitable for use in recombination cloning according to the present invention. However, wild-type recombination sites may contain sequences that reduce the efficiency or specificity of recombination reactions or the function of the Product molecules as applied in methods of the present invention. For example, multiple stop codons in attB, attR, attP, attL and loxP recombination sites occur in multiple reading frames on both strands, so translation efficiencies are reduced, *e.g.*, where the coding sequence must cross the recombination sites, (only one reading frame is available on each strand of loxP and attB sites) or impossible (in attP, attR or attL).

20 Accordingly, the present invention also provides engineered recombination sites that overcome these problems. For example, att sites can be engineered to have one or multiple mutations to enhance specificity or efficiency of the recombination reaction and the properties of Product DNAs (*e.g.*, att1, att2, and att3 sites); to decrease reverse reaction (*e.g.*, removing P1 and H1 from attR). The testing of these mutants determines which mutants yield sufficient 25 recombinational activity to be suitable for recombination subcloning according to the present invention.

30 Mutations can therefore be introduced into recombination sites for enhancing site specific recombination. Such mutations include, but are not limited to: recombination sites without translation stop codons that allow fusion proteins to be encoded; recombination sites recognized by the same proteins but differing in base sequence such that they react largely or exclusively with their homologous partners allowing multiple reactions to be contemplated; and mutations that

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5 prevent hairpin formation of recombination sites. Which particular reactions take place can be specified by which particular partners are present in the reaction mixture. For example, a tripartite protein fusion could be accomplished with parental plasmids containing recombination sites attR1 and attL1; and attB3; attR1; attP3 and 10xP; and/or attR3 and 10xP; and/or attR3 and attL2.

10 There are well known procedures for introducing specific mutations into nucleic acid sequences. A number of these are described in Ausubel, F.M. *et al.*, *Current Protocols in Molecular Biology*, Wiley Interscience, New York (1989-1996). Mutations can be designed into oligonucleotides, which can be used to modify existing cloned sequences, or in amplification reactions. Random 15 mutagenesis can also be employed if appropriate selection methods are available to isolate the desired mutant DNA or RNA. The presence of the desired mutations can be confirmed by sequencing the nucleic acid by well known methods.

20 The following non-limiting methods can be used to modify or mutate a core region of a given recombination site to provide mutated sites that can be used in the present invention:

1. By recombination of two parental DNA sequences by site-specific (e.g. attL and attR to give attB) or other (e.g. homologous) recombination mechanisms where the parental DNA segments contain one or more base alterations resulting in the final mutated core sequence;
2. By mutation or mutagenesis (site-specific, PCR, random, spontaneous, etc) directly of the desired core sequence;
- 25 3. By mutagenesis (site-specific, PCR, random, spontaneous, etc) of parental DNA sequences, which are recombined to generate a desired core sequence;
4. By reverse transcription of an RNA encoding the desired core sequence; and
- 30 5. By de novo synthesis (chemical synthesis) of a sequence having the desired base changes.

The functionality of the mutant recombination sites can be demonstrated in ways that depend on the particular characteristic that is desired. For example, the lack of translation stop codons in a recombination site can be demonstrated by expressing the appropriate fusion proteins. Specificity of recombination between homologous partners can be demonstrated by introducing the appropriate molecules into *in vitro* reactions, and assaying for recombination products as described herein or known in the art. Other desired mutations in recombination sites might include the presence or absence of restriction sites, translation or transcription start signals, protein binding sites, and other known functionalities of nucleic acid base sequences. Genetic selection schemes for particular functional attributes in the recombination sites can be used according to known method steps. For example, the modification of sites to provide (from a pair of sites that do not interact) partners that do interact could be achieved by requiring deletion, via recombination between the sites, of a DNA sequence encoding a toxic substance. Similarly, selection for sites that remove translation stop sequences, the presence or absence of protein binding sites, etc., can be easily devised by those skilled in the art.

Accordingly, the present invention provides a nucleic acid molecule, comprising at least one DNA segment having at least two engineered recombination sites flanking a Selectable marker and/or a desired DNA segment, wherein at least one of said recombination sites comprises a core region having at least one engineered mutation that enhances recombination *in vitro* in the formation of a Cointegrate DNA or a Product DNA.

While in the preferred embodiment the recombination sites differ in sequence and do not interact with each other, it is recognized that sites comprising the same sequence can be manipulated to inhibit recombination with each other. Such conceptions are considered and incorporated herein. For example, a protein binding site can be engineered adjacent to one of the sites. In the presence of the protein that recognizes said site, the recombinase fails to access the site and the other site is therefore used preferentially. In the cointegrate this site can no longer react since it has been changed e.g. from attB to attL. In resolution of the

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cointegrate, the protein can be inactivated (e.g. by antibody, heat or a change of buffer) and the second site can undergo recombination.

The nucleic acid molecule can have at least one mutation that confers at least one enhancement of said recombination, said enhancement selected from the group consisting of substantially (i) favoring integration; (ii) favoring recombination; (ii) relieving the requirement for host factors; (iii) increasing the efficiency of said Cointegrate DNA or Product DNA formation; and (iv) increasing the specificity of said Cointegrate DNA or Product DNA formation.

The nucleic acid molecule preferably comprises at least one recombination site derived from attB, attP, attL or attR, such as attR' or attP'. More preferably the att site is selected from att1, att2, or att3, as described herein.

In a preferred embodiment, the core region comprises a DNA sequence selected from the group consisting of:

- (a) RKYCWGCTTYKTRTACNAASTSGB (m-att) (SEQ ID NO:1);
- (b) AGCCWGCTTYKTRTACNAACTSGB (m-attB) (SEQ ID NO:2);
- (c) GTTCAGCTTCKTRTACNAACTSGB (m-attR) (SEQ ID NO:3);
- (d) AGCCWGCTTCKTRTACNAAGTSGB (m-attL) (SEQ ID NO:4);
- (e) GTTCAGCTTYKTRTACNAAGTSGB (m-attP1) (SEQ ID NO:5);
- (f) RBYCW GCTTYTTRTACWAA STKGD (n-att) (SEQ ID NO:39);
- (g) ASCCW GCTTYTTRTACWAA STKGW (n-attB) (SEQ ID NO:40);
- (h) ASCCW GCTTYTTRTACWAA GTTGG (n-attL) (SEQ ID NO:41);
- (i) GTTCA GCTTYTTRTACWAA STKGW (n-attR) (SEQ ID NO:42);
- (j) GTTCA GCTTYTTRTACWAA GTTGG (n-attP) (SEQ ID NO:43);

or a corresponding or complementary DNA or RNA sequence, wherein R=A or G; K=G or T/U; Y=C or T/U; W=A or T/U; N=A or C or G or T/U; S=C or G; and B=C or G or T/U, as presented in 37 C.F.R. §1.822, which is entirely incorporated herein by reference, wherein the core region does not contain a stop codon in one or more reading frames.

5 The core region also preferably comprises a DNA sequence selected from the group consisting of:

- (a) AGCCTGCTTTTGTACAAACTTGT (attB1) (SEQ ID NO:6);
- (b) AGCCTGCTTCTTGTACAAACTTGT (attB2) (SEQ ID NO:7);
- 10 (c) ACCCAGCTTCTTGTACAAAGTGGT (attB3) (SEQ ID NO:8);
- (d) GTTCAGCTTTTGTACAAACTTGT (attR1) (SEQ ID NO:9);
- (e) GTTCAGCTTCTTGTACAAACTTGT (attR2) (SEQ ID NO:10);
- 15 (f) GTTCAGCTTCTTGTACAAAGTGGT (attR3) (SEQ ID NO:11);
- (g) AGCCTGCTTTTGTACAAAGTTGG (attL1) (SEQ ID NO:12);
- (h) AGCCTGCTTCTTGTACAAAGTTGG (attL2) (SEQ ID NO:13);
- 20 (i) ACCCAGCTTCTTGTACAAAGTTGG (attL3) (SEQ ID NO:14);
- (j) GTTCAGCTTTTGTACAAAGTTGG (attP1) (SEQ ID NO:15);
- (k) GTTCAGCTTCTTGTACAAAGTTGG (attP2,P3) (SEQ ID NO:16); or a corresponding or complementary DNA or RNA sequence.

25 The present invention thus also provides a method for making a nucleic acid molecule, comprising providing a nucleic acid molecule having at least one engineered recombination site comprising at least one DNA sequence having at least 80-99% homology (or any range or value therein) to at least one of the above sequences, or any suitable recombination site, or which hybridizes under stringent conditions thereto, as known in the art.

Clearly, there are various types and permutations of such well-known *in vitro* and *in vivo* selection methods, each of which are not described herein for the sake of brevity. However, such variations and permutations are contemplated and considered to be the different embodiments of the present invention.

5 It is important to note that as a result of the preferred embodiment being *in vitro* recombination reactions, non-biological molecules such as PCR products can be manipulated via the present recombinational cloning method. In one example, it is possible to clone linear molecules into circular vectors.

10 There are a number of applications for the present invention. These uses include, but are not limited to, changing vectors, apposing promoters with genes, constructing genes for fusion proteins, changing copy number, changing replicons, cloning into phages, and cloning, *e.g.*, PCR products (with an *attB* site at one end and a *loxP* site at the other end), genomic DNAs, and cDNAs.

15 ***Vector Donors***

20 In accordance with the invention, any vector may be used to construct the Vector Donors of the invention. In particular, vectors known in the art and those commercially available (and variants or derivatives thereof) may in accordance with the invention be engineered to include one or more recombination sites for use in the methods of the invention. Such vectors may be obtained from, for example, Vector Laboratories Inc., InVitrogen, Promega, Novagen, NEB, Clontech, Boehringer Mannheim, Pharmacia, EpiCenter, OriGenes Technologies Inc., Stratagene, Perkin Elmer, Pharmingen, Life Technologies, Inc., and Research Genetics. Such vectors may then for example be used for cloning or subcloning 25 nucleic acid molecules of interest. General classes of vectors of particular interest include prokaryotic and/or eukaryotic cloning vectors, expression vectors, fusion vectors, two-hybrid or reverse two-hybrid vectors, shuttle vectors for use in different hosts, mutagenesis vectors, transcription vectors, vectors for receiving large inserts and the like.

30 Other vectors of interest include viral origin vectors (M13 vectors, bacterial phage λ vectors, adenovirus vectors, and retrovirus vectors), high, low and adjustable copy number vectors, vectors which have compatible replicons for

use in combination in a single host (pACYC184 and pBR322) and eukaryotic episomal replication vectors (pCDM8).

Particular vectors of interest include prokaryotic expression vectors such as pcDNA II, pSL301, pSE280, pSE380, pSE420, pTrcHisA, B, and C, pRSET A, B, and C (Invitrogen, Inc.), pGEMEX-1, and pGEMEX-2 (Promega, Inc.), the pET vectors (Novagen, Inc.), pTrc99A, pKK223-3, the pGEX vectors, pEZ18, pRIT2T, and pMC1871 (Pharmacia, Inc.), pKK233-2 and pKK388-1 (Clontech, Inc.), and pProEx-HT (Life Technologies, Inc.) and variants and derivatives thereof. Vector donors can also be made from eukaryotic expression vectors such as pFastBac, pFastBac HT, pFastBac DUAL, pSFV, and pTet-Splice (Life Technologies, Inc.), pEUK-C1, pPUR, pMAM, pMAMneo, pBI101, pBI121, pDR2, pCMVEBNA, and pYACneo (Clontech), pSVK3, pSVL, pMSG, pCH110, and pKK232-8 (Pharmacia, Inc.), p3'SS, pXT1, pSG5, pPbac, pMbac, pMC1neo, and pOG44 (Stratagene, Inc.), and pYES2, pAC360, pBlueBacHis A, B, and C, pVL1392, pBsueBacIII, pCDM8, pcDNA1, pZeoSV, pcDNA3 pREP4, pCEP4, and pEBVHis (Invitrogen, Inc.) and variants or derivatives thereof.

Other vectors of particular interest include pUC18, pUC19, pBlueScript, pSPORT, cosmids, phagemids, YAC's (yeast artificial chromosomes), BAC's (bacterial artificial chromosomes), P1 (*E. coli* phage), pQE70, pQE60, pQE9 (quagan), pBS vectors, PhageScript vectors, BlueScript vectors, pNH8A, pNH16A, pNH18A, pNH46A (Stratagene), pcDNA3 (InVitrogen), pGEX, pTrsfus, pTrc99A, pET-5, pET-9, pKK223-3, pKK233-3, pDR540; pRIT5 (Pharmacia), pSPORT1, pSPORT2, pCMVSPORT2.0 and pSV-SPORT1 (Life Technologies, Inc.) and variants or derivatives thereof.

Additional vectors of interest include pTrxFus, pThioHis, pLEX, pTrcHis, pTrcHis2, pRSET, pBlueBacHis2, pcDNA3.1/His, pcDNA3.1(-)/Myc-His, pSecTag, pEBVHis, pPIC9K, pPIC3.5K, pAO815, pPICZ, pPICZ α , pGAPZ, pGAPZ α , pBlueBac4.5, pBlueBacHis2, pMelBac, pSinRep5, pSinHis, pIND, pIND(SP1), pVgRXR, pcDNA2.1. pYES2, pZErO1.1, pZErO-2.1, pCR-Blunt, pSE280, pSE380, pSE420, pVL1392, pVL1393, pCDM8, pcDNA1.1, pcDNA1.1/Amp, pcDNA3.1, pcDNA3.1/Zeo, pSe, SV2, pRc/CMV2, pRc/RSV, pREP4, pREP7, pREP8, pREP9, pREP10, pCEP4, pEBVHis, pCR3.1, pCR2.1,

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5 pCR3.1-Uni, and pCRBac from Invitrogen; λ ExCell, λ gt11, pTrc99A, pKK223-3, pGEX-1 λ T, pGEX-2T, pGEX-2TK, pGEX-4T-1, pGEX-4T-2, pGEX-4T-3, pGEX-3X, pGEX-5X-1, pGEX-5X-2, pGEX-5X-3, pEZZ18, pRIT2T, pMC1871, pSVK3, pSVL, pMSG, pCH110, pKK232-8, pSL1180, pNEO, and pUC4K from Pharmacia; pSCREEN-1b(+), pT7Blue(R), pT7Blue-2, pCITE-4abc(+), pOCUS-2, pTAg, pET-32LIC, pET-30LIC, pBAC-2cpLIC, pBACgus-2cpLIC, pT7Blue-2LIC, pT7Blue-2, λ SCREEN-1, λ BlueSTAR, pET-3abcd, pET-7abc, pET9abcd, pET11abcd, pET12abc, pET-14b, pET-15b, pET-16b, pET-17b- pET-17xb, pET-19b, pET-20b(+), pET-21abcd(+), pET-22b(+), pET-10 23abcd(+), pET-24abcd(+), pET-25b(+), pET-26b(+), pET-27b(+), pET-28abc(+), pET-29abc(+), pET-30abc(+), pET-31b(+), pET-32abc(+), pET-33b(+), pBAC-1, pBACgus-1, pBAC4x-1, pBACgus4x-1, pBAC-3cp, pBACgus-2cp, pBACsurf-1, plg, Signal plg, pYX, Selecta Vecta-Neo, Selecta Vecta - Hyg, and Selecta Vecta - Gpt from Novagen; pLexA, pB42AD, pGBT9, pAS2-1, pGAD424, pACT2, pGAD GL, pGAD GH, pGAD10, pGilda, pEZM3, pEGFP, pEGFP-1, pEGFP-N, pEGFP-C, pEBFP, pGFPuv, pGFP, p6xHis-GFP, pSEAP2-Basic, pSEAP2-Contral, pSEAP2-Promoter, pSEAP2-Enhancer, p β gal-Basic, p β gal-Control, p β gal-Promoter, p β gal-Enhancer, pCMV β , pTet-Off, pTet-On, pTK-Hyg, pRetro-Off, pRetro-On, pIRES1neo, pIRES1hyg, pLXSN, pLNCX, pLAPSN, pMAMneo, pMAMneo-CAT, pMAMneo-LUC, pPUR, pSV2neo, pYEX 4T-1/2/3, pYEX-S1, pBacPAK-His, pBacPAK8/9, pAcUW31, BacPAK6, pTriplEx, λ gt10, λ gt11, pWE15, and λ TriplEx from Clontech; Lambda ZAP II, pBK-CMV, pBK-RSV, pBluescript II KS +/-, pBluescript II SK +/-, pAD-GAL4, pBD-GAL4 Cam, pSurfscript, Lambda FIX II, Lambda DASH, Lambda EMBL3, 15 Lambda EMBL4, SuperCos, pCR-Script Amp, pCR-Script Cam, pCR-Script Direct, pBS +/-, pBC KS +/-, pBC SK +/-, Phagescript, pCAL-n-EK, pCAL-n, pCAL-c, pCAL-kc, pET-3abcd, pET-11abcd, pSPUTK, pESP-1, pCMVLaci, pOPRSVI/MCS, pOPI3 CAT, pXT1, pSG5, pPbac, pMbac, pMC1neo, pMC1neo Poly A, pOG44, pOG45, pFRT β GAL, pNEO β GAL, pRS403, pRS404, pRS405, 20 pRS406, pRS413, pRS414, pRS415, and pRS416 from Stratagene.

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Two-hybrid and reverse two-hybrid vectors of particular interest include pPC86, pDBLeu, pDBTrp, pPC97, p2.5, pGAD1-3, pGAD10, pACt, pACT2,

pGADGL, pGADGH, pAS2-1, pGAD424, pGBT8, pGBT9, pGAD-GAL4, pLexA, pBD-GAL4, pHISi, pHISi-1, placZi, pB42AD, pDG202, pJK202, pJG4-5, pNLexA, pYESTrp and variants or derivatives thereof.

5

Polymerases

Preferred polypeptides having reverse transcriptase activity (*i.e.*, those polypeptides able to catalyze the synthesis of a DNA molecule from an RNA template) include, but are not limited to Moloney Murine Leukemia Virus (M-MLV) reverse transcriptase, Rous Sarcoma Virus (RSV) reverse transcriptase, Avian Myeloblastosis Virus (AMV) reverse transcriptase, Rous Associated Virus (RAV) reverse transcriptase, Myeloblastosis Associated Virus (MAV) reverse transcriptase, Human Immunodeficiency Virus (HIV) reverse transcriptase, retroviral reverse transcriptase, retrotransposon reverse transcriptase, hepatitis B reverse transcriptase, cauliflower mosaic virus reverse transcriptase and bacterial reverse transcriptase. Particularly preferred are those polypeptides having reverse transcriptase activity that are also substantially reduced in RNase H activity (*i.e.*, "RNase H⁻" polypeptides). By a polypeptide that is "substantially reduced in RNase H activity" is meant that the polypeptide has less than about 20%, more preferably less than about 15%, 10% or 5%, and most preferably less than about 2%, of the RNase H activity of a wildtype or RNase H⁺ enzyme such as wildtype M-MLV reverse transcriptase. The RNase H activity may be determined by a variety of assays, such as those described, for example, in U.S. Patent No. 5,244,797, in Kotewicz, M.L. *et al.*, *Nucl. Acids Res.* 16:265 (1988) and in Gerard, G.F., *et al.*, *FOCUS* 14(5):91 (1992), the disclosures of all of which are fully incorporated herein by reference. Suitable RNase H⁻ polypeptides for use in the present invention include, but are not limited to, M-MLV H⁻ reverse transcriptase, RSV H⁻ reverse transcriptase, AMV H⁻ reverse transcriptase, RAV H⁻ reverse transcriptase, MAV H⁻ reverse transcriptase, HIV H⁻ reverse transcriptase, and SUPERSCRIPTTM I reverse transcriptase and SUPERSCRIPTTM II reverse transcriptase which are available commercially, for example from Life Technologies, Inc. (Rockville, Maryland).

Other polypeptides having nucleic acid polymerase activity suitable for use in the present methods include thermophilic DNA polymerases such as DNA polymerase I, DNA polymerase III, Klenow fragment, T7 polymerase, and T5 polymerase, and thermostable DNA polymerases including, but not limited to, *Thermus thermophilus* (*Tth*) DNA polymerase, *Thermus aquaticus* (*Taq*) DNA polymerase, *Thermotoga neopolitana* (*Tne*) DNA polymerase, *Thermotoga maritima* (*Tma*) DNA polymerase, *Thermococcus litoralis* (*Tli* or VENT®) DNA polymerase, *Pyrococcus furiosus* (*Pfu* or DEEPVENT®) DNA polymerase, *Pyrococcus woosii* (*Pwo*) DNA polymerase, *Bacillus stearothermophilus* (*Bst*) DNA polymerase, *Sulfolobus acidocaldarius* (*Sac*) DNA polymerase, *Thermoplasma acidophilum* (*Tac*) DNA polymerase, *Thermus flavus* (*Tfl/Tub*) DNA polymerase, *Thermus ruber* (*Tru*) DNA polymerase, *Thermus brockianus* (DYNAZYME®) DNA polymerase, *Methanobacterium thermoautotrophicum* (*Mth*) DNA polymerase, and mutants, variants and derivatives thereof.

It will be understood by one of ordinary skill in the relevant arts that other suitable modifications and adaptations to the methods and applications described herein are readily apparent and may be made without departing from the scope of the invention or any embodiment thereof. Having now described the present invention in detail, the same will be more clearly understood by reference to the following examples, which are included herewith for purposes of illustration only and are not intended to be limiting of the invention.

Examples

The present recombinational cloning method accomplishes the exchange of nucleic acid segments to render something useful to the user, such as a change of cloning vectors. These segments must be flanked on both sides by recombination signals that are in the proper orientation with respect to one another. In the examples below the two parental nucleic acid molecules (e.g., plasmids) are called the Insert Donor and the Vector Donor. The Insert Donor contains a segment that will become joined to a new vector contributed by the Vector Donor. The recombination intermediate(s) that contain(s) both starting

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molecules is called the Cointegrate(s). The second recombination event produces two daughter molecules, called the Product (the desired new clone) and the Byproduct.

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Buffers

Various known buffers can be used in the reactions of the present invention. For restriction enzymes, it is advisable to use the buffers recommended by the manufacturer. Alternative buffers can be readily found in the literature or can be devised by those of ordinary skill in the art.

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Examples 1-3. One exemplary buffer for lambda integrase is comprised of 50 mM Tris-HCl, at pH 7.5-7.8, 70 mM KCl, 5 mM spermidine, 0.5 mM EDTA, and 0.25 mg/ml bovine serum albumin, and optionally, 10% glycerol.

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One preferred buffer for P1 Cre recombinase is comprised of 50 mM Tris-HCl at pH 7.5, 33 mM NaCl, 5 mM spermidine, and 0.5 mg/ml bovine serum albumin.

The buffer for other site-specific recombinases which are similar to lambda Int and P1 Cre are either known in the art or can be determined empirically by the skilled artisans, particularly in light of the above-described buffers.

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Example 1: Recombinational Cloning Using Cre and Cre & Int

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Two pairs of plasmids were constructed to do the *in vitro* recombinational cloning method in two different ways. One pair, pEZC705 and pEZC726 (Figure 2A), was constructed with *loxP* and *att* sites, to be used with Cre and λ integrase. The other pair, pEZC602 and pEZC629 (Figure 3A), contained the *loxP* (wild type) site for Cre, and a second mutant *lox* site, *loxP 511*, which differs from *loxP* in one base (out of 34 total). The minimum requirement for recombinational cloning of the present invention is two recombination sites in each plasmid, in general *X* and *Y*, and *X'* and *Y'*. Recombinational cloning takes place if either or both types of site can recombine to form a Cointegrate (e.g. *X* and *X'*), and if either or both can recombine to excise the Product and Byproduct plasmids

from the Cointegrate (e.g. Y and Y'). It is important that the recombination sites on the same plasmid do not recombine. It was found that the present recombinational cloning could be done with Cre alone.

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Cre-Only

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Two plasmids were constructed to demonstrate this conception (see Figure 3A). pEYC629 was the Vector Donor plasmid. It contained a constitutive drug marker (chloramphenicol resistance), an origin of replication, *loxP* and *loxP 511* sites, a conditional drug marker (kanamycin resistance whose expression is controlled by the operator/promoter of the tetracycline resistance operon of transposon *Tn10*), and a constitutively expressed gene for the tet repressor protein, *tetR*. *E. coli* cells containing pEYC629 were resistant to chloramphenicol at 30 μ g/ml, but sensitive to kanamycin at 100 μ g/ml. pEYC602 was the Insert Donor plasmid, which contained a different drug marker (ampicillin resistance), an origin, and *loxP* and *loxP 511* sites flanking a multiple cloning site.

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This experiment was comprised of two parts as follows:

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Part I: About 75 ng each of pEYC602 and pEYC629 were mixed in a total volume of 30 μ l of Cre buffer (50 mM Tris-HCl pH 7.5, 33 mM NaCl, 5 mM spermidine-HCl, 500 μ g/ml bovine serum albumin). Two 10 μ l aliquots were transferred to new tubes. One tube received 0.5 μ l of Cre protein (approx. 4 units per μ l; partially purified according to Abremski and Hoess, *J. Biol. Chem.* 259:1509 (1984)). Both tubes were incubated at 37°C for 30 minutes, then 70°C for 10 minutes. Aliquots of each reaction were diluted and transformed into DH5 α . Following expression, aliquots were plated on 30 μ g/ml chloramphenicol; 100 μ g/ml ampicillin plus 200 μ g/ml methicillin; or 100 μ g/ml kanamycin.

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Results: See Table 1. The reaction without Cre gave 1.11×10^6 ampicillin resistant colonies (from the Insert Donor plasmid pEYC602); 7.8×10^5 chloramphenicol resistant colonies (from the Vector Donor plasmid pEYC629); and 140 kanamycin resistant colonies (background). The reaction with added Cre gave 7.5×10^5 ampicillin resistant colonies (from the Insert Donor plasmid pEYC602); 6.1×10^5 chloramphenicol resistant colonies (from the Vector Donor plasmid pEYC629);

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and 760 kanamycin resistant colonies (mixture of background colonies and colonies from the recombinational cloning Product plasmid). *Analysis:* Because the number of colonies on the kanamycin plates was much higher in the presence of Cre, many or most of them were predicted to contain the desired Product plasmid.

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Table 1

Enzyme	Ampicillin	Chloramphenicol	Kanamycin	Efficiency
None	1.1×10^6	7.8×10^5	140	$140 / 7.8 \times 10^5 = 0.02\%$
Cre	7.5×10^5	6.1×10^5	760	$760 / 6.1 \times 10^5 = 0.12\%$

Part II: Twenty four colonies from the "+ Cre" kanamycin plates were picked and inoculated into medium containing 100 μ g/ml kanamycin. Minipreps were done, and the miniprep DNAs, uncut or cut with *Sma*I or *Hind*III, were electrophoresed. **Results:** 19 of the 24 minipreps showed supercoiled plasmid of the size predicted for the Product plasmid. All 19 showed the predicted *Sma*I and *Hind*III restriction fragments. **Analysis:** The Cre only scheme was demonstrated. Specifically, it was determined to have yielded about 70% (19 of 24) Product clones. The efficiency was about 0.1% (760 kanamycin resistant clones resulted from 6.1×10^5 chloramphenicol resistant colonies).

Cre Plus Integrase

The plasmids used to demonstrate this method are exactly analogous to those used above, except that pEZC726, the Vector Donor plasmid, contained an *attP* site in place of *loxP 511*, and pEZC705, the Insert Donor plasmid, contained an *attB* site in place of *loxP 511* (Figure 2A).

This experiment was comprised of three parts as follows:

Part I: About 500 ng of pEZC705 (the Insert Donor plasmid) was cut with *Scal*I, which linearized the plasmid within the ampicillin resistance gene. (This was done because the λ integrase reaction has been historically done with the *attB* plasmid in a linear state (H. Nash, personal communication). However, it was

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found later that the integrase reaction proceeds well with both plasmids supercoiled.) Then, the linear plasmid was ethanol precipitated and dissolved in 20 μ l of λ integrase buffer (50 mM Tris-HCl, about pH 7.8, 70 mM KCl, 5 mM spermidine-HCl, 0.5 mM EDTA, 250 μ g/ml bovine serum albumin). Also, about 500 ng of the Vector Donor plasmid pEZC726 was ethanol precipitated and dissolved in 20 μ l λ integrase buffer. Just before use, λ integrase (2 μ l, 393 μ g/ml) was thawed and diluted by adding 18 μ l cold λ integrase buffer. One μ l IHF (integration host factor, 2.4 mg/ml, an accessory protein) was diluted into 150 μ l cold λ integrase buffer. Aliquots (2 μ l) of each DNA were mixed with λ integrase buffer, with or without 1 μ l each λ integrase and IHF, in a total of 10 μ l. The mixture was incubated at 25°C for 45 minutes, then at 70°C for 10 minutes. Half of each reaction was applied to an agarose gel. **Results:** In the presence of integrase and IHF, about 5% of the total DNA was converted to a linear Cointegrate form. **Analysis:** Activity of integrase and IHF was confirmed.

15 **Part II:** Three microliters of each reaction (*i.e.*, with or without integrase and IHF) were diluted into 27 μ l of Cre buffer (above), then each reaction was split into two 10 μ l aliquots (four altogether). To two of these reactions, 0.5 μ l of Cre protein (above) were added, and all reactions were incubated at 37°C for 30 minutes, then at 70°C for 10 minutes. TE buffer (90 μ l; TE: 10 mM Tris-HCl, pH 7.5, 1 mM EDTA) was added to each reaction, and 1 μ l each was transformed into *E. coli* DH5 α . The transformation mixtures were plated on 100 μ g/ml ampicillin plus 200 μ g/ml methicillin; 30 μ g/ml chloramphenicol; or 100 μ g/ml kanamycin. **Results:** See Table 2.

Table 2				
Enzyme	Ampicillin	Chloramphenicol	Kanamycin	Efficiency
None	990	20000	4	$4 / 2 \times 10^4 = 0.02\%$
Cre only	280	3640	0	0
Integrase * only	1040	27000	9	$9 / 2.7 \times 10^4 = 0.03\%$
Integrase * + Cre	110	1110	76	$76 / 1.1 \times 10^3 = 6.9\%$

* Integrase reactions also contained IHF.

Analysis: The Cre protein impaired transformation. When adjusted for this effect, the number of kanamycin resistant colonies, compared to the control reactions, increased more than 100 fold when both Cre and Integrase were used. This suggests a specificity of greater than 99%.

Part III: 38 colonies were picked from the Integrase plus Cre plates, miniprep DNAs were made and cut with *Hind*III to give diagnostic mapping information. *Result:* All 38 had precisely the expected fragment sizes. *Analysis:* The Cre plus λ integrase method was observed to have much higher specificity than Cre-alone. *Conclusion:* The Cre plus λ integrase method was demonstrated. Efficiency and specificity were much higher than for Cre only.

Example 2: Using in vitro Recombinational Cloning to Subclone the Chloramphenicol Acetyl Transferase Gene into a Vector for Expression in Eukaryotic Cells (Figure 4A)

An Insert Donor plasmid, pEYC843, was constructed, comprising the chloramphenicol acetyl transferase gene of *E. coli*, cloned between *loxP* and *attB* sites such that the *loxP* site was positioned at the 5'-end of the gene (Figure 4B). A Vector Donor plasmid, pEYC1003, was constructed, which contained the cytomegalovirus eukaryotic promoter apposed to a *loxP* site (Figure 4C). One microliter aliquots of each supercoiled plasmid (about 50 ng crude miniprep DNA) were combined in a ten microliter reaction containing equal parts of lambda

integrase buffer (50 mM Tris-HCl, pH 7.8, 70 mM KCl, 5 mM spermidine, 0.5 mM EDTA, 0.25 mg/ml bovine serum albumin) and Cre recombinase buffer (50 mM Tris-HCl, pH 7.5, 33 mM NaCl, 5 mM spermidine, 0.5 mg/ml bovine serum albumin), two units of Cre recombinase, 16 ng integration host factor, and 32 ng lambda integrase. After incubation at 30°C for 30 minutes and 75°C for 10 minutes, one microliter was transformed into competent *E. coli* strain DH5 α (Life Technologies, Inc.). Aliquots of transformations were spread on agar plates containing 200 μ g/ml kanamycin and incubated at 37°C overnight. An otherwise identical control reaction contained the Vector Donor plasmid only. The plate receiving 10% of the control reaction transformation gave one colony; the plate receiving 10% of the recombinational cloning reaction gave 144 colonies. These numbers suggested that greater than 99% of the recombinational cloning colonies contained the desired product plasmid. Miniprep DNA made from six recombinational cloning colonies gave the predicted size plasmid (5026 base pairs), CMVProd. Restriction digestion with *Nco*I gave the fragments predicted for the chloramphenicol acetyl transferase cloned downstream of the CMV promoter for all six plasmids.

Example 3: Subcloned DNA Segments Flanked by attB Sites Without Stop Codons

Part I: Background

The above examples are suitable for transcriptional fusions, in which transcription crosses recombination sites. However, both attR and loxP sites contain multiple stop codons on both strands, so translational fusions can be difficult, where the coding sequence must cross the recombination sites, (only one reading frame is available on each strand of loxP sites) or impossible (in attR or attL).

A principal reason for subcloning is to fuse protein domains. For example, fusion of the glutathione S-transferase (GST) domain to a protein of interest allows the fusion protein to be purified by affinity chromatography on glutathione agarose (Pharmacia, Inc., 1995 catalog). If the protein of interest is fused to runs

of consecutive histidines (for example His6), the fusion protein can be purified by affinity chromatography on chelating resins containing metal ions (Qiagen, Inc.). It is often desirable to compare amino terminal and carboxy terminal fusions for activity, solubility, stability, and the like.

5 The attB sites of the bacteriophage λ integration system were examined as an alternative to loxP sites, because they are small (25 bp) and have some sequence flexibility (Nash, H.A. *et al.*, *Proc. Natl. Acad. Sci. USA* 84:4049-4053 (1987). It was not previously suggested that multiple mutations to remove all stop codes would result in useful recombination sites for recombinational subcloning.

10 Using standard nomenclature for site specific recombination in lambda bacteriophage (Weisber, in *Lambda III*, Hendrix, *et al.*, eds., Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1989)), the nucleotide regions that participate in the recombination reaction in an *E. coli* host cell are represented as follows:

15 attP --P1--H1--P2--X--H2--C-O-C'--H'--P'1--P'2--P'3--
+
attB --B-O-B'--
Int, IHF $\Downarrow\Updownarrow$ Xis, Int, IHF

20 attR --P1--H1--P2--X--H2--C-O-B'--
+
attL --B-O-C'--H'--P'1--P'2--P'3--,

25 where: O represents the 15 bp core DNA sequence found in both the phage and *E. coli* genomes; B and B' represent approximately 5 bases adjacent to the core in the *E. coli* genome; and P1, H1, P2, X, H2, C, C', H', P'1, P'2, and P'3 represent known DNA sequences encoding protein binding domains in the bacteriophage λ genome.

30 The reaction is reversible in the presence of the protein Xis (excisionase); recombination between attL and attR precisely excise the λ genome from its integrated state, regenerating the circular λ genome containing attP and the linear *E. coli* genome containing attB.

Part II: Construction and Testing of Plasmids Containing Mutant att Sites

Mutant attL and attR sites were constructed. Importantly, Landy *et al.* (*Ann. Rev. Biochem.* 58:913 (1989)) observed that deletion of the P1 and H1 domains of attP facilitated the excision reaction and eliminated the integration reaction, thereby making the excision reaction irreversible. Therefore, as mutations were introduced in attR, the P1 and H1 domains were also deleted. attR' sites in the present example lack the P1 and H1 regions and have the NdeI site removed (base 27630 changed from C to G), and contain sequences corresponding to bacteriophage λ coordinates 27619-27738 (GenBank release 92.0, bg:LAMCG, "Complete Sequence of Bacteriophage Lambda").

The sequence of attB produced by recombination of wild type attL and attR sites is:

15	B	O	B'	
	attBwt : 5' AGCCT	GCTTTTTT <u>TATACTAA</u>	CTT <u>G</u> A 3'	(SEQ.
				ID
				NO: 60)
20	3' TCGGA	CGAAAA <u>AATATGATT</u>	GAAC	5' (SEQ.
				ID
				NO: 44)

The stop codons are italicized and underlined. Note that sequences of attL, attR, and attP can be derived from the attB sequence and the boundaries of bacteriophage λ contained within attL and attR (coordinates 27619 to 27818).

When mutant attR1 (attR') and attL1 sites were recombined the sequence attB1 was produced (mutations in **bold, large font**):

30	B	O	B'	
	attB1 : 5' AGCCT	GCTTTTTT G TAC <u>AAA</u>	CTT G T 3'	(SEQ.
				ID
				NO: 6)
25	3' TCGGA	CGAAAA <u>ACATG</u> T TT	GAAC <u>A</u> 5'	(SEQ.
				ID
				NO: 45)

Note that the four stop codons are gone.

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When an additional mutation was introduced in the attR1 (attR') and attL1 sequences (**bold**), attR2 (attR') and attL2 sites resulted. Recombination of attR2 and attL2 produced the attB2 site:

The recombination activities of the above attL and attR' sites were assayed as follows. The attB site of plasmid pEZC705 (Figure 2B) was replaced with attLwt, attL1, or attL2. The attP site of plasmid pEZC726 (Figure 2C) was replaced with attRwt, attR1 (attR', lacking regions P1 and H1) or attR2 (attR', lacking regions P1 and H1). Thus, the resulting plasmids could recombine via their loxP sites, mediated by Cre, and via their attR' and attL sites, mediated by Int, Xis, and IHF. Pairs of plasmids were mixed and reacted with Cre, Int, Xis, and IHF, transformed into *E. coli* competent cells, and plated on agar containing kanamycin. The results are presented in Table 3:

Table 3

Vector donor att site	Gene donor att site	# of kanamycin resistant colonies*
attR' wt (pEZC1301)	None	1 (background)
"	attLwt (pEZC1313)	147
"	attL1 (pEZC1317)	47
"	attL2 (pEZC1321)	0
attR' 1 (pEZC1305)	None	1 (background)
"	attLwt (pEZC1313)	4
"	attL1 (pEZC1317)	128
"	attL2 (pEZC1321)	0
attR' 2 (pEZC1309)	None	0 (background)
"	attLwt (pEZC1313)	0
"	attL1 (pEZC1317)	0
"	attL2 (pEZC1321)	209

(*1% of each transformation was spread on a kanamycin plate.)

The above data show that whereas the wild type att and att1 sites recombine to a small extent, the att1 and att2 sites do not recombine detectably with each other.

Part III. Recombination was demonstrated when the core region of both attB sites flanking the DNA segment of interest did not contain stop codons. The physical state of the participating plasmids was discovered to influence recombination efficiency.

The appropriate att sites were moved into pEZC705 and pEZC726 to make the plasmids pEZC1405 (Figure 5G) (attR' 1 and attR' 2) and pEZC1502 (Figure 5H) (attL1 and attL2). The desired DNA segment in this experiment was a copy of the chloramphenicol resistance gene cloned between the two attL sites of pEZC1502. Pairs of plasmids were recombined *in vitro* using Int, Xis, and IHF (no Cre because no loxP sites were present). 100 ng of each plasmid were incubated in 10 µl reactions of 50 mM Tris HCl pH about 7.8, 16.5 mM NaCl, 35 mM KCl, 5 mM spermidine, 0.25 mM EDTA, 0.375 mg/ml BSA, 3% glycerol that contained 8.1 ng IHF, 43 ng Int, 4.3 ng Xis, and 2 units Cre. Reactions were incubated at 25°C for 45 min., 65°C for 10 min, and 1 µl aliquots were transformed into DH5α cells, and spread on kanamycin plates. The yield of

desired kanamycin resistant colonies was determined when both parental plasmids were circular, or when one plasmid was circular and the other linear as presented in Table 4:

5 **Table 4**

Vector donor ¹	Insert donor ¹	Kanamycin resistant colonies ²
Circular pEZC1405	None	30
Circular pEZC1405	Circular pEZC1502	2680
Linear pEZC1405	None	90
Linear pEZC1405	Circular pEZC1502	172000
Circular pEZC1405	Linear pEZC1502	73000

15 ¹ DNAs were purified with Qiagen columns, concentrations determined by A260, and linearized with XbaI (pEZC1405) or AlwNI (pEZC1502). Each reaction contained 100 ng of the indicated DNA. All reactions (10 μ l total) contained 3 μ l of enzyme mix (Xis, Int, and IHF). After incubation (45 minutes at 25°, 10 minutes at 65°), one μ l was used to transform *E. coli* DH5 α cells.

20 ² Number of colonies expected if the entire transformation reaction (1 ml) had been plated. Either 100 μ l or 1 μ l of the transformations were actually plated.

25 **Analysis:** Recombinational cloning using mutant attR and attL sites was confirmed. The desired DNA segment is subcloned between attB sites that do not contain any stop codons in either strand. The enhanced yield of Product DNA (when one parent was linear) was unexpected because of earlier observations that the excision reaction was more efficient when both participating molecules were supercoiled and proteins were limiting (Nunes-Duby *et al.*, *Cell* 50:779-788 30 (1987).

Example 4: Demonstration of Recombinational Cloning Without Inverted Repeats

35 **Part I: Rationale**

The above Example 3 showed that plasmids containing inverted repeats of the appropriate recombination sites (for example, attL1 and attL2 in plasmid pEZC1502) (Figure 5H) could recombine to give the desired DNA segment flanked by attB sites without stop codons, also in inverted orientation. A concern

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was the *in vivo* and *in vitro* influence of the inverted repeats. For example, transcription of a desired DNA segment flanked by attB sites in inverted orientation could yield a single stranded RNA molecule that might form a hairpin structure, thereby inhibiting translation.

5 Inverted orientation of similar recombination sites can be avoided by placing the sites in direct repeat arrangement att sites. If parental plasmids each have a wild type attL and wild type attR site, in direct repeat the Int, Xis, and IHF proteins will simply remove the DNA segment flanked by those sites in an intramolecular reaction. However, the mutant sites described in the above
10 Example 3 suggested that it might be possible to inhibit the intramolecular reaction while allowing the intermolecular recombination to proceed as desired.

15 ***Part II: Structure of Plasmids Without Inverted Repeats for Recombinational Cloning***

The attR2 sequence in plasmid pEZC1405 (Figure 5G) was replaced with attL2, in the opposite orientation, to make pEZC1603 (Figure 6A). The attL2 sequence of pEZC1502 (Figure 5H) was replaced with attR2, in the opposite orientation, to make pEZC1706 (Figure 6B). Each of these plasmids contained mutations in the core region that make intramolecular reactions between att1 and att2 cores very inefficient (see Example 3, above).

20 Plasmids pEZC1405, pEZC1502, pEZC1603 and pEZC1706 were purified on Qiagen columns (Qiagen, Inc.). Aliquots of plasmids pEZC1405 and pEZC1603 were linearized with XbaI. Aliquots of plasmids pEZC1502 and pEZC1706 were linearized with AlwNI. One hundred ng of plasmids were mixed in buffer (50 mM Tris HCl pH about 7.8, 16.5 mM NaCl, 35 mM KCl, 5 mM spermidine, 0.25 mM EDTA, 0.375 mg/ml BSA, 3% glycerol) containing Int (43.5 ng), Xis (4.3 ng) and IHF (8.1 ng) in a final volume of 10 μ l. Reactions were incubated for 45 minutes at 25°C, 10 minutes at 65°C, and 1 μ l was transformed into *E. coli* DH5 α . After expression, aliquots were spread on agar plates containing 200 μ g/ml kanamycin and incubated at 37°C.

30 Results, expressed as the number of colonies per 1 μ l of recombination reaction are presented in Table 5:

Table 5

Vector Donor	Gene Donor	Colonies	Predicted % product
Circular 1405	---	100	---
Circular 1405	Circular 1502	3740	3640/3740 = 97%
Linear 1405	---	90	---
Linear 1405	Circular 1502	172,000	171,910/172,000 = 99.9%
Circular 1405	Linear 1502	73,000	72,900/73,000 = 99.9%
Circular 1603	---	80	---
Circular 1603	Circular 1706	410	330/410 = 80%
Linear 1603	---	270	---
Linear 1603	Circular 1706	7000	6730/7000 = 96%
Circular 1603	Linear 1706	10,800	10,530/10,800 = 97%

Analysis. In all configurations, i.e., circular or linear, the pEZC1405 x pEZC1502 pair (with att sites in inverted repeat configuration) was more efficient than pEZC1603 x pEZC1706 pair (with att sites mutated to avoid hairpin formation). The pEZC1603 x pEZC1706 pair gave higher backgrounds and lower efficiencies than the pEZC1405 x pEZC1502 pair. While less efficient, 80% or more of the colonies from the pEZC1603 x pEZC1706 reactions were expected to contain the desired plasmid product. Making one partner linear stimulated the reactions in all cases.

Part III: Confirmation of Product Plasmids' Structure

Six colonies each from the linear pEZC1405 (Figure 5G) x circular pEZC1502 (Figure 5H), circular pEZC1405 x linear pEZC1502, linear pEZC1603 (Figure 6A) x circular pEZC1706 (Figure 6B), and circular pEZC1603 x linear pEZC1706 reactions were picked into rich medium and miniprep DNAs were prepared. Diagnostic cuts with Ssp I gave the predicted restriction fragments for all 24 colonies.

Analysis. Recombination reactions between plasmids with mutant attL and attR sites on the same molecules gave the desired plasmid products with a high degree of specificity.

5

Example 5: Recombinational Cloning with a Toxic Gene

Part I: Background

10 Restriction enzyme DpnI recognizes the sequence GATC and cuts that sequence only if the A is methylated by the dam methylase. Most commonly used *E. coli* strains are dam⁺. Expression of DpnI in dam⁺ strains of *E. coli* is lethal because the chromosome of the cell is chopped into many pieces. However, in dam⁻ cells expression of DpnI is innocuous because the chromosome is immune to DpnI cutting.

15 In the general recombinational cloning scheme, in which the vector donor contains two segments C and D separated by recombination sites, selection for the desired product depends upon selection for the presence of segment D, and the absence of segment C. In the original Example segment D contained a drug resistance gene (Km) that was negatively controlled by a repressor gene found on segment C. When C was present, cells containing D were not resistant to kanamycin because the resistance gene was turned off.

20 25 The DpnI gene is an example of a toxic gene that can replace the repressor gene of the above embodiment. If segment C expresses the DpnI gene product, transforming plasmid CD into a dam⁺ host kills the cell. If segment D is transferred to a new plasmid, for example by recombinational cloning, then selecting for the drug marker will be successful because the toxic gene is no longer present.

Part II: Construction of a Vector Donor Using DpnI as a Toxic Gene

30 The gene encoding DpnI endonuclease was amplified by PCR using primers 5'CCA CCA CAA ACG CGT CCA TGG AAT TAC ACT TTA ATT TAG3' (SEQ. ID NO: 17) and 5'CCA CCA CAA GTC GAC GCA TGC CGA

CAG CCT TCC AAA TGT3' (SEQ ID NO:18) and a plasmid containing the DpnI gene (derived from plasmids obtained from Sanford A. Lacks, Brookhaven National Laboratory, Upton, New York; also available from American Type Culture Collection as ATCC 67494) as the template.

5 Additional mutations were introduced into the B and B' regions of attL and attR', respectively, by amplifying existing attL and attR' domains with primers containing the desired base changes. Recombination of the mutant attL3 (made with oligo Xis115) and attR'3 (attR', made with oligo Xis112) yielded attB3 with the following sequence (differences from attB1 in bold):

10

B	O	B'	
ACCC A	GCTTT CTTGTACAAA	GTGGT	(SEQ ID NO: 8)
TGGGT	CGAAAGAACATGTTT	CACCA	(SEQ ID NO: 47)

15 The attL3 sequence was cloned in place of attL2 of an existing Gene Donor plasmid to give the plasmid pEYC2901 (Figure 7A). The attR'3 sequence was cloned in place of attR'2 in an existing Vector Donor plasmid to give plasmid pEYC2913 (Figure 7B). The DpnI gene was cloned into plasmid pEYC2913 to replace the tet repressor gene. The resulting Vector Donor plasmid was named pEYC3101 (Figure 7C). When pEYC3101 was transformed into the dam⁻ strain SCS110 (Stratagene), hundreds of colonies resulted. When the same plasmid was transformed into the dam⁺ strain DH5 α , only one colony was produced, even though the DH5 α cells were about 20 fold more competent than the SCS110 cells. When a related plasmid that did not contain the DpnI gene was transformed into the same two cell lines, 28 colonies were produced from the SCS110 cells, while 25 448 colonies resulted from the DH5 α cells. This is evidence that the Dpn I gene is being expressed on plasmid pEYC3101 (Figure 7C), and that it is killing the dam⁺ DH5 α cells but not the dam⁻ SCS110 cells.

Part III: Demonstration of Recombinational Cloning Using *DpnI* Selection

A pair of plasmids was used to demonstrate recombinational cloning with selection for Product dependent upon the toxic gene *DpnI*. Plasmid pEYC3101 (Figure 7C) was linearized with *Mlu*I and reacted with circular plasmid pEYC2901 (Figure 7A). A second pair of plasmids using selection based on control of drug resistance by a repressor gene was used as a control: plasmid pEYC1802 (Figure 7D) was linearized with *Xba*I and reacted with circular plasmid pEYC1502 (Figure 5H). Eight microliter reactions containing buffer (50 mM Tris HCl pH about 7.8, 16.5 mM NaCl, 35 mM KCl, 5 mM spermidine, 0.375 mg/ml BSA, 0.25 mM EDTA, 2.5% glycerol) and proteins Xis (2.9 ng), Int (29 ng), and IHF (5.4 ng) were incubated for 45 minutes at 25°C, then 10 minutes at 75°C, and 1 μ l aliquots were transformed into DH5 α (i.e., *dam*⁺) competent cells, as presented in Table 6.

Table 6

Reaction #	Vector donor	Basis of selection	Insert donor	Colonies
1	pEYC3101/ <i>Mlu</i>	<i>Dpn I</i> toxicity	---	3
2	pEYC3101/ <i>Mlu</i>	<i>Dpn I</i> toxicity	Circular pEYC2901	4000
3	pEYC1802/ <i>Xba</i>	Tet repressor	---	0
4	pEYC1802/ <i>Xba</i>	Tet repressor	Circular pEYC1502	12100

Miniprep DNAs were prepared from four colonies from reaction #2, and cut with restriction enzyme *Ssp* I. All gave the predicted fragments.

Analysis: Subcloning using selection with a toxic gene was demonstrated. Plasmids of the predicted structure were produced.

Example 6: Cloning of Genes with Uracil DNA Glycosylase and Subcloning of the Genes with Recombinational Cloning to Make Fusion Proteins

5 **Part I: Converting an Existing Expression Vector to a Vector Donor for Recombinational Cloning**

A cassette useful for converting existing vectors into functional Vector Donors was made as follows. Plasmid pEZR3101 (Figure 7C) was digested with ApaI and KpnI, treated with T4 DNA polymerase and dNTPs to render the ends blunt, further digested with SmaI, HpaI, and AlwNI to render the undesirable DNA fragments small, and the 2.6 kb cassette containing the attR' 1 - Cm^R - Dpn I - attR' -3 domains was gel purified. The concentration of the purified cassette was estimated to be about 75 ng DNA/μl.

15 Plasmid pGEX-2TK (Figure 8A) (Pharmacia) allows fusions between the protein glutathione S transferase and any second coding sequence that can be inserted in frame in its multiple cloning site. pGEX-2TK DNA was digested with SmaI and treated with alkaline phosphatase. About 75 ng of the above purified DNA cassette was ligated with about 100 ng of the pGEX-2TK vector for 2.5 hours in a 5 μl ligation, then 1 μl was transformed into competent *E. coli* BRL 3056 cells (a dam⁻ derivative of DH10B; dam⁻ strains commercially available include DM1 from Life Technologies, Inc., and SCS 110 from Stratagene). Aliquots of the transformation mixture were plated on LB agar containing 100 μg/ml ampicillin (resistance gene present on pGEX-2TK) and 30 μg/ml chloramphenicol (resistance gene present on the DNA cassette). Colonies were 20 picked and miniprep DNAs were made. The orientation of the cassette in pGEX-2TK was determined by diagnostic cuts with EcoRI. A plasmid with the desired orientation was named pEZR3501 (Figure 8B).

25 **Part II: Cloning Reporter Genes Into an Recombinational Cloning Gene Donor Plasmid in Three Reading Frames**

30 Uracil DNA glycosylase (UDG) cloning is a method for cloning PCR amplification products into cloning vectors (U.S. patent No. 5,334,515, entirely incorporated herein by reference). Briefly, PCR amplification of the desired DNA

5 segment is performed with primers that contain uracil bases in place of thymidine bases in their 5' ends. When such PCR products are incubated with the enzyme UDG, the uracil bases are specifically removed. The loss of these bases weakens base pairing in the ends of the PCR product DNA, and when incubated at a suitable temperature (e.g., 37°C), the ends of such products are largely single stranded. If such incubations are done in the presence of linear cloning vectors containing protruding 3' tails that are complementary to the 3' ends of the PCR products, base pairing efficiently anneals the PCR products to the cloning vector. When the annealed product is introduced into *E. coli* cells by transformation, *in* 10 *vivo* processes efficiently convert it into a recombinant plasmid.

15 UDG cloning vectors that enable cloning of any PCR product in all three reading frames were prepared from pEZC3201 (Figure 8K) as follows. Eight oligonucleotides were obtained from Life Technologies, Inc. (all written 5' → 3'): **rf1 top** (GGCC GAT TAC GAT ATC CCA ACG ACC GAA AAC CTG TAT TTT CAG GGT) (SEQ. ID NO:19), **rf1 bottom** (CAG GTT TTC GGT CGT TGG GAT ATC GTA ATC) (SEQ. ID NO:20), **rf2 top** (GGCCA GAT TAC GAT ATC CCA ACG ACC GAA AAC CTG TAT TTT CAG GGT) (SEQ. ID NO:21), **rf2 bottom** (CAG GTT TTC GGT CGT TGG GAT ATC GTA ATC T) (SEQ. ID NO:22), **rf3 top** (GGCCAA GAT TAC GAT ATC CCA ACG ACC GAA AAC CTG TAT TTT CAG GGT) (SEQ. ID NO:23), **rf3 bottom** (CAG GTT TTC GGT CGT TGG GAT ATC GTA ATC TT) (SEQ. ID NO:24), **carboxy top** (ACC GTT TAC GTG GAC) (SEQ. ID NO:25) and **carboxy bottom** (TCGA GTC CAC GTA AAC GGT TCC CAC TTA TTA) (SEQ. ID NO:26). The rf1, 2, and 3 top strands and the carboxy bottom strand were phosphorylated on their 5' ends with T4 polynucleotide kinase, and then the complementary strands of each pair were hybridized. Plasmid pEZC3201 (Figure 8K) was cut with NotI and SalI, and aliquots of cut plasmid were mixed with the carboxy-oligo duplex (Sal I end) and either the rf1, rf2, or rf3 duplexes (NotI ends) (10 µg cut plasmid (about 5 pmol) mixed with 250 pmol carboxy oligo duplex, split into three 20 µl volumes, added 5 µl (250 pmol) of rf1, rf2, or rf3 duplex and 2 µl = 2 units T4 DNA ligase to each reaction). After 90 minutes 20 25 30

of ligation at room temperature, each reaction was applied to a preparative agarose gel and the 2.1 kb vector bands were eluted and dissolved in 50 μ l of TE.

Part III: PCR of CAT and phoA Genes

5 Primers were obtained from Life Technologies, Inc., to amplify the chloramphenicol acetyl transferase (CAT) gene from plasmid pACYC184, and phoA, the alkaline phosphatase gene from *E. coli*. The primers had 12-base 5' extensions containing uracil bases, so that treatment of PCR products with uracil DNA glycosylase (UDG) would weaken base pairing at each end of the DNAs and allow the 3' strands to anneal with the protruding 3' ends of the rf1, 2, and 3 vectors described above. The sequences of the primers (all written 5' \rightarrow 3') were: **CAT left**, UAU UUU CAG GGU ATG GAG AAA AAA ATC ACT GGA TAT ACC (SEQ. ID NO:27); **CAT right**, UCC CAC UUA UUA CGC CCC GCC CTG CCA CTC ATC (SEQ. ID NO:28); **phoA left**, UAU UUU CAG GGU ATG CCT GTT CTG GAA AAC CGG (SEQ. ID NO:29); and **phoA right**, UCC CAC UUA UUA TTT CAG CCC CAG GGC GGC TTT C (SEQ. ID NO:30).
10 The primers were then used for PCR reactions using known method steps (see, e.g., U.S. patent No. 5,334,515, entirely incorporated herein by reference), and the polymerase chain reaction amplification products obtained with these primers comprised the CAT or phoA genes with the initiating ATGs but without any transcriptional signals. In addition, the uracil-containing sequences on the amino 15 termini encoded the cleavage site for TEV protease (Life Technologies, Inc.), and those on the carboxy terminal encoded consecutive TAA nonsense codons.
20

25 Unpurified PCR products (about 30 ng) were mixed with the gel purified, linear rf1, rf2, or rf3 cloning vectors (about 50 ng) in a 10 μ l reaction containing 1X REact 4 buffer (LTI) and 1 unit UDG (LTI). After 30 minutes at 37°C, 1 μ l aliquots of each reaction were transformed into competent *E. coli* DH5 α cells (LTI) and plated on agar containing 50 μ g/ml kanamycin. Colonies were picked and analysis of miniprep DNA showed that the CAT gene had been cloned in reading frame 1 (pEZR3601) (Figure 8C), reading frame 2 (pEZR3609) 30 (Figure 8D) and reading frame 3 (pEZR3617) (Figure 8E), and that the phoA gene

had been cloned in reading frame 1 (pEZC3606) (Figure 8F), reading frame 2 (pEZC3613) (Figure 8G) and reading frame 3 (pEZC3621) (Figure 8H).

5 **Part IV: Subcloning of CAT or phoA from UDG Cloning Vectors into a GST Fusion Vector**

10 Plasmids encoding fusions between GST and either CAT or phoA in all three reading frames were constructed by recombinational cloning as follows. Miniprep DNA of GST vector donor pEZC3501 (Figure 8B) (derived from Pharmacia plasmid pGEX-2TK as described above) was linearized with *Cla*I. About 5 ng of vector donor were mixed with about 10 ng each of the appropriate circular gene donor vectors containing CAT or phoA in 8 μ l reactions containing buffer and recombination proteins Int, Xis, and IHF (Example 5). After incubation, 1 μ l of each reaction was transformed into *E. coli* strain DH5 α and plated on ampicillin, as presented in Table 7.

15

20 **Table 7**

DNA	Colonies (10% of each transformation)
Linear vector donor (pEZC3501/ <i>Cla</i>)	0
Vector donor + CAT rf1	110
Vector donor + CAT rf2	71
Vector donor + CAT rf3	148
Vector donor + phoA rf1	121
Vector donor + phoA rf2	128
Vector donor + phoA rf3	31

35 **Part V: Expression of Fusion Proteins**

40 Two colonies from each transformation were picked into 2 ml of rich medium (CircleGrow, Bio101 Inc.) in 17 \times 100 mm plastic tubes (Falcon 2059, Becton Dickinson) containing 100 μ g/ml ampicillin and shaken vigorously for about 4 hours at 37°C, at which time the cultures were visibly turbid. One ml of each culture was transferred to a new tube containing 10 μ l of 10% (w/v) IPTG

5

to induce expression of GST. After 2 hours additional incubation, all cultures had about the same turbidity; the A600 of one culture was 1.5. Cells from 0.35 ml each culture were harvested and treated with sample buffer (containing SDS and β -mercaptoethanol) and aliquots equivalent to about 0.15 A600 units of cells were applied to a Novex 4-20% gradient polyacrylamide gel. Following electrophoresis the gel was stained with Coomassie blue.

10

Results: Enhanced expression of single protein bands was seen for all 12 cultures. The observed sizes of these proteins correlated well with the sizes predicted for GST being fused (through attB recombination sites without stop codons) to CAT (Figure 8I) or phoA (Figure 8J) in three reading frames: CAT rf1 = 269 amino acids; CAT rf2 = 303 amino acids; CAT rf3 = 478 amino acids; phoA rf1 = 282 amino acids; phoA rf2 = 280 amino acids; and phoA rf3 = 705 amino acids.

15

Analysis: Both CAT and phoA genes were subcloned into a GST fusion vector in all three reading frames, and expression of the six fusion proteins was demonstrated.

20

Example 7: Reverse Recombination and Subcloning by Recombination

Two plasmids were constructed to demonstrate reverse recombination according to the present invention. The vector pEZC5601 (Figure 10A), containing attB recombination sites and termed the *attB parent* plasmid (this vector may correspond to the Product DNA), further contained an ampicillin resistance gene, an origin of replication, an attB2 site, a tetracycline resistance gene, and an attB0 site, as described above. Plasmid pEZC6701 (Figure 10B), containing attP recombination sites and termed the *attP parent* plasmid (this vector may correspond to the Byproduct DNA or may correspond to a different Vector Donor DNA), also contained a kanamycin resistance gene, an origin of replication, an attP2 site, a gene encoding the toxic protein ccdB, and an attP0 site. Integrase buffer at 10 X concentration comprised 0.25 M Tris HCl pH 7.5, 0.25 M Tris HC1 pH 8.0, 0.7 M potassium chloride, 50 mM spermidine HC1, 5mM EDTA, and 2.5 mg /ml BSA. Note that attP0 and attP2 contained the P1

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and H1 domains. Integrase (1.5 μ l of 435 ng / μ l) and IHF (1.5 μ l of 16 ng / μ l in 1 X Integrase buffer) were mixed with 13.5 μ l of 1 X Int buffer to make the recombinase mixture.

Two 8 μ l reactions were assembled. Reaction A contained 300 ng pEYC6701 plasmid and 2 μ l of recombinase mixture in 1 X Integrase buffer. Reaction B contained 300 ng pEYC5601, 300 ng pEYC6701, and 2 μ l of recombinase mixture in 1 X Integrase buffer. Both reactions were incubated at 25 °C for 45 minutes, then at 70 °C for 5 minutes, and then cooled. TE buffer (792 μ l of 10 mM Tris HC1 pH 7.5, 1 mM EDTA) was added to each reaction, and 1 μ l of this diluted reaction was transformed into DH5 α UltraMax competent *E. coli* cells (Life Technologies, Inc., Rockville, MD). After 1 hour of expression in non-selective medium, one tenth (100 μ l) of each transformation was spread onto agar plates containing 100 μ g/ml kanamycin.

After overnight incubation at 37 °C, the plate from reaction A contained 1 colony, while the plate from reaction B contained 392 colonies. Twelve colonies were picked from the reaction B plate into rich liquid medium and grown overnight. Miniprep DNAs prepared from these cultures were run uncut on an agarose gel and all 12 contained a plasmid of about 3.8 kb. Six of the miniprep DNAs were cut with restriction enzyme Clal and run along with pEYC6701 (the kanamycin resistant parental plasmid) also cut with Clal. Plasmid pEYC6701 was cut once with Clal to give a fragment of about 3.8 kb. The six miniprep DNAs cut twice with Clal to give fragments of about 900 base pairs and about 2900 base pairs.

Analysis: Recombination between the attP sites on pEYC6701 and the attB sites on pEYC5601 resulted in the production of two daughter plasmids, the *attL product* plasmid (Figure 10C) (which may correspond to the Vector Donor DNA or a new Byproduct DNA) that contained the ampicillin resistance and ccdB genes, and the *attR product* plasmid (Figure 10D) (which may also correspond to the Insert Donor DNA or a new Product DNA) that contained the kanamycin and tetracycline resistance genes. Competent *E. coli* cells that received the *attL product* plasmid, the *attP parent* plasmid pEYC6701, or recombination intermediates, were killed by the toxic ccdB gene product. Competent *E. coli* cells

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that received the *attB parent* plasmid pEYC5601 were killed by the kanamycin selection. Only competent *E. coli* cells that received the desired *attR product* plasmid, comprising the kanamycin and tetracycline resistance genes, survived to form colonies. The success of the selection strategy was indicated by the large 5 number of colonies from the reaction that contained both parental plasmids, compared to the reaction that contained only one parental plasmid. The reaction mechanism predicted that the desired product plasmid would contain two *Cla*I restriction sites, one in the kanamycin resistance gene from the pEYC6701 *attP* parent plasmid and one in the tetracycline resistance gene from the pEYC5601 *attB parent* plasmid. The presence of the two sites and the sizes of the fragments 10 resulting from the *Cla*I digestion confirmed the reaction mechanism.

Thus, the present invention relates to reversal of the recombination reaction shown in Figure 1, in which the Product DNA and Byproduct DNA may be combined to produce the Insert Donor DNA and the Vector Donor DNA. 15 Additionally, the invention provides for subcloning recombinations, in which a Product DNA (produced according to Figure 1) may be combined with a new Vector Donor DNA to produce a new Product DNA (in a different Vector background) and a new Byproduct.

20 ***Example 8: Subcloning of Linearized Fragments***

Plasmid pEYC7102 (Figure 11A), the *attP parent* plasmid (which may correspond to the Vector Donor DNA), contained segments *attP1*, origin of 25 replication, kanamycin resistance, *attP3*, chloramphenicol resistance, and the toxic gene *ccdB*, and in the experiment described here was supercoiled. Plasmid pEYC7501 (Figure 11B), the *attB parent* plasmid (which may correspond to the Insert Donor DNA or the Product DNA), contained the GFP gene cloned between *attB 1* and *attB3* sites in a vector that comprised the functional domains of 30 pCMVSPORT2.0 (Life Technologies, Inc.). The *attP* sites contained the *P1* and *H1* domains. Plasmid pEYC7501 was used uncut, or was linearized within the ampicillin resistance gene with *Sca*I, or was cut with *Xba*I and *Sall*, to yield a

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fragment comprising the SalI end, 22bp, the attB1 site, the GFP gene, the attB3 site, and 14 bp to the XbaI end:

SalI end -- 22bp -- attB1 -- GFP -- attB3 -- 14bp -- XbaI end

5

10

Reactions (8 μ l final volume) contained about 40 ng of each DNA, 1 X Int buffer (25 mM Tris HCl pH 7.5, 25 mM Tris HCl pH 8.0, 70 mM KCl, 5 mM spermidine HCl, 0.5 mM EDTA, and 0.25 mg/ml BSA), 12.5% glycerol, 8 ng IHF, and 43 ng lambda integrase. Reactions were incubated at 25 °C for 45 minutes, then at 70 °C for 5 minutes, and then cooled. Duplicate 1 μ l aliquots of each reaction were transformed into DH5 α UltraMax cells and plated in duplicate on kanamycin agar plates.

15

20

The reaction that contained only (supercoiled) pEZC7102 gave an average of 2 colonies (range 1 to 4). The reaction that contained both pEZC7102 and supercoiled pEZC7501 gave an average of 612 colonies (range 482 - 762). The reaction that contained pEZC7102 and linear (ScaI-cut) pEZC7501 gave an average of 360 colonies (range 127-605). The reaction that contained pEZC7102 and the GFP gene on a fragment with attB sites and 22bp and 14 bp beyond the attB sites (pEZC7501 cut with SalI and XbaI) gave an average of 274 colonies (range 243-308).

25

Miniprep DNAs were prepared from 4 colonies from the pEZC7102 x supercoiled pEZC7510 reaction, and from 10 colonies from the pEZC7102 x pEZC7501/SalI + XbaI reaction. All 14 DNAs were run uncut on an agarose gel, and the 10 DNAs from the pEZC7102 x pEZC7501/SalI + XbaI reaction were cut with a mixture of NcoI and PstI and run on an agarose gel. All the uncut plasmids were about 2.8 kb in size. All ten plasmids cut with the mixture of NcoI and PstI gave fragments of about 700 and 2100 bp.

The results are presented in Table 8:

30

Table 8

attP Parent	attB Parent	Colonies (average of 4 plates)	Minipreps done	Uncut product plasmid size	Fragment sizes, Nco + Pst digest
sc 7102	--	2	--	--	--
sc 7102	sc 7501	612	4	2.8 kb	--
sc 7102	7501/ScaI	360	--	--	--
sc 7102	7501/SalI + XbaI	274	10	2.8 kb	ca. 2100 bp, 700 bp

Analysis: It was expected that the integrative reaction between the attB sites on plasmid pEYC7501 and the attP sites on plasmid pEYC7102 would produce the *attL product* plasmid (Figure 11C) (corresponding to the Insert Donor DNA) containing the GFP segment from pEYC7501, and the kanamycin - origin segment from pEYC7102. The presence of the toxic gene ccdB on the *attP parent* plasmid pEYC7102 (corresponding to the Byproduct DNA) was predicted to kill all the cells that received this plasmid. The large increase in the number of colonies when pEYC7501 was present indicated that the desired reaction was occurring, and that the efficiency of the reaction was adequate even if the *attB parent* plasmid (corresponding to the Product DNA) was linear (ScaI cut), or if the attB sites and the GFP gene were present in a fragment that contained little additional sequence beyond the attB sites.

These results show that linear fragments can be suitably subcloned into a different vector by the method of the invention.

Example 9: Cloning Long PCR Fragments

A PCR product was designed to have an attB0 (wild type) site at one end and a loxP site at the other end. The rationale was that the attP0 x attB0 reaction would go well with the attB0 molecule (the PCR product) linear, (since it involves a normal lambda integration reaction), and that the loxP x loxP excision from the

cointegrate would also be efficient (the unimolecular excision reaction is efficient, the bimolecular integration reaction is inefficient with Cre).

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The sequence of the attB-containing PCR primer was 5'-TCC GTT GAA GCC TGC TTT TTT ATA CTA ACT TGA GCG AAG CCT CGG GGT CAG CAT AAG G-3' (SEQ ID NO:31). The sequence of the loxP primer was 5'-CCA ATA ACT TCG TAT AGC ATA CAT TAT ACG AAG TTA TTG CCC CTT GGT GAC ATA CTC G-3' (SEQ ID NO:32). These primers amplify a part of the human myosin heavy chain. Polymerase chain reactions were performed using ELONGASE™ and K562 human DNA as template. Polymerase chain reactions were performed as follows. Reactions (50 microliters) contained 100 ng K562 human DNA (Life Technologies, Inc.), 0.2 μ M of each primer, and 0.2 mM of each dNTP, in ELONGASE™ SuperMix (Life Technologies, Inc.). Reactions in thin wall tubes under mineral oil were denatured at 94°C for 1 minute, then cycled 35 times at 94°C for 30 seconds, 65°C for 30 seconds, and 68°C for 8 minutes 30 seconds. Following thermal cycling, reactions were maintained at 4°C. The 5.2 kb PCR product (Figure 9A) was gel purified.

Plasmid pEZC1202 (Figure 9B) contained a wild-type attP site, a chloramphenicol resistance gene, a gene encoding the tet repressor, a wild-type loxP site, an origin of replication, and a tet operator/promoter transcribing and controlling the transcription of a kanamycin resistance gene. This plasmid conferred chloramphenicol resistance but not kanamycin resistance, because the tet repressor made by one element of the plasmid kept the kanamycin resistance gene turned off. The pEZC1202 DNA used in this experiment was a miniprep whose concentration was estimated to be about 50 ng per microliter.

About 40 ng of the gel purified 5.2 kb PCR product were included in a 10 μ l reaction that contained about 50 ng of supercoiled pEZC1202, 0.2 units of Cre recombinase, 3.6 ng IHF, and 11 ng of Int in 50 mM Tris HC1 pH about 7.8, 16 mM NaCl, 35 mM KC1, 0.25 mM EDTA, 0.375 mg/ml bovine serum albumin. A second reaction that did not contain the PCR product was included as a control. After incubating at 27° for 45 min and then 70° for 5 minutes, 1 μ l aliquots were transformed into DH5 α UltraMax competent *E. coli* cells (Life Technologies, Inc.). One fifth of each expression mix was plated on agar that contained

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100 µg/ml kanamycin and the plates were incubated overnight at 37° C. The reaction that contained the PCR product gave 34 colonies, while the reaction that lacked the PCR product gave 31 colonies. After the plates sat at room temperature for four days, 26 additional small colonies were seen on the plate from the positive (+ PCR product) reaction, while only one additional small colony was seen on the plate from the negative (no PCR product) reaction.

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Twelve of the 26 small colonies were grown overnight in rich broth (CircleGrow) that contained 25 µg/ml kanamycin, and miniprep DNAs were prepared from these cultures. All twelve miniprep plasmids were about 8 kb in size, which corresponded to the size expected for replacement of the choramphenicol resistance and tet repressor genes in pEZC1202 with the 5.2 kb PCR product. The predicted recombinant product is shown in Figure 9C. Two of these plasmids were cut with *Ava*I (8 sites predicted) and *Bam*HI (4 sites predicted). All the predicted *Ava*I fragments appeared to be present. One of the *Bam*H I sites predicted in the PCR product (the one closest to the *att*B end) was absent from both minipreps, but the other *Bam*HI fragments were consistent with the expected structure of the cloned 5.2 kb PCR product.

Analysis: The replacement of the choramphenicol resistance and tet

repressor genes in pEZC1202 with the 5.2 kb PCR product (part of the human myosin heavy chain) conferred a moderate resistance of the host *E. coli* cells to kanamycin, but this resistance was not sufficient to allow colonies to appear after overnight incubation. Thus, colonies containing the desired recombination product grew on kanamycin plates, but were not seen after overnight incubation, but only after an additional room temperature incubation. Of the 12 *Ava*I and *Bam*HI restriction sites predicted from the nucleotide sequence, 11 were confirmed experimentally. Thus the following three observations support the conclusion that the 5.2 kb PCR product was cloned by recombination: (a) small, slow growing colonies appeared only on the plate from the reaction that contained the PCR product; (b) the miniprep plasmids from these colonies were the expected size; and (c) diagnostic restriction cuts gave the expected fragments (with the one above noted exception).

Example 10: Cloning of PCR Fragments

Three sets of pairs of PCR primers (Table 9) were designed to amplify an 830 bp sequence within plasmid pEZC7501 (Figure 11B) comprising: attB 1--GFP--attB3, with or without additional nucleotides at the outer ends of the 25 bp attB1 and attB3 recombination sites. (Here "outer" refers to the end of the attB sequence that is not adjacent to the GFP gene sequence.) Primer set A added 17 nucleotides upstream of attB1 and 15 nucleotides downstream of attB3; primer set B added 5 and 8 nucleotides to attB1 and attB3, respectively; and primer set C added no additional nucleotides to either attB recombination sequence.

The primer sequences are provided in Table 9:

Table 9

upper GFP A	5'-TCA CTA GTC GGC GGC CCA CA (SEQ ID NO:33)
lower GFP A	5'-GAG CGG CCC CCG CGG ACC AC (SEQ ID NO:34)
upper GFP B	5'-GGC CCA CAA GTT TGT ACA AAA (SEQ ID NO:35)
lower GFP B	5'-CCC CGC GGA CCA CTT TGT AC (SEQ ID NO:36)
upper GFP C	5'-ACA AGT TTG TAC AAA AAA GCA (SEQ ID NO:37)
lower GFP C	5'-ACC ACT TTG TAC AAG AAA GCT (SEQ ID NO:38)

PCR Reactions

Primer sets A and C were used first with the following PCR reactions, in 50 μ l, in duplicate. Final concentrations were:

20 mM TrisHCl, pH 8.4

50 mM KC1

0.2mM of all four deoxynucleotide triphosphates (dNTPs)

400 ng/ml pEZC7501 supercoiled DNA template

0.5 μ M of each primer

Recombinant Taq DNA polymerase (BRL-GIBCO) 100 U/ml

A duplicate set of the above reactions contained 1 M betaine.

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The reactions were first heated for to 94°C for 1', then cycled 25 times at 94°C for 45", 55°C for 30", and 72°C for 1'.

5 The size of the PCR reaction products was analyzed on a 1% agarose gel in TAE buffer containing 0.5 µg/ml ethidium bromide. All reactions yielded products of the expected size, thus duplicate reactions were pooled. As the corresponding reactions with and without betaine were not significantly different, these also were pooled, giving a final pooled volume for reactions with primer sets A and C of 200 µl each.

10 Primer set B was then used with identical reactions to those above performed, except that the reaction volumes were increased to 100µl. After duplicate reactions and reactions plus and minus betaine were pooled, the final volume of the reactions with primer set B was 400 µl.

15 The three pooled primer reaction products were stored at -20°C for 4 weeks.

PCR Product Purification

20 Each of the three pooled PCR products was extracted once with an equal volume of a mixture of Tris-buffered phenol, isoamyl alcohol and chloroform. The aqueous supernatant then was extracted twice with an equal volume of isobutanol, and the aqueous layer ethanol precipitated with two volumes of ethanol, 0.1 M sodium acetate, pH 6.2. The ethanol precipitates were recovered by centrifugation at 13,000 rpm for 10' at room temperature, and the supernatant discarded. The dried pellets were dissolved in TE: 100µl for reactions prepared with primer sets A and C; 200 µl for the reactions with primer set B.

25 To remove PCR primers and extraneous small PCR products, the PCR products were precipitated with polyethylene glycol (PEG) by adding ½ volume of a solution of 30% PEG 8000 (Sigma), 30 mM MgCl₂, mixing well, and centrifuging at 13,000 rpm for 10', all at room temperature. The supernatant was discarded, and the pellets were dissolved in their previous volume of TE buffer. 30 1 µl aliquots of each of the three PCR products were checked on a 1% agarose gel to quantitate the recovery, which was estimated to be over 90%. The concentration of each PCR product was adjusted using TE to 40 ng/µl.

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Recombination Reaction with the PCR Products of Primer sets A, B, and C

Five 8 μ l reactions were assembled in 1 X Integrase buffer (25 mM Tris HCl pH 7.5, 25 mM Tris HCl pH 8.0, 80 mM KCl, 5 mM spermidine, 0.5 mM EDTA, 0.25 mg/ml BSA) containing: 40 ng of pEZC7102 DNA, 2 μ l of recombinase mixture (8 ng/ μ l IHF, 22 ng/ μ l Int in 1 X Int Buffer, 50% glycerol) the reactions differed by the addition of either the PCR product of primer set A (reaction A), primer set B (reaction B), or primer set C (reaction C); the addition of no PCR product (reaction D), or the addition of 40 ng of pEZC7501 SC (supercoiled) DNA(reaction E) as a positive control. All reactions were performed in duplicate.

The reactions were incubated for 45' at 25°C, for 10' at 70°C, then held at 0-5°C. 2 μ l aliquots of each reaction were transformed into Max Efficiency DH5 α , in a 50 μ l transformation reaction, and following expression in 50C medium, 1/5 (100 μ l) and 4/5 (400 μ l) of the reactions were plated on kanamycin-containing (50 μ g/ml) LB culture plates. The results of the duplicate reactions are shown in Table 10.

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Transfection	No. Colonies
A 100 μ l	464, 668
A 400 μ l	>1000, >1300
B 100 μ l	980, 1292
B 400 μ l	>3000, >3000
C 100 μ l	2, 8
C 400 μ l	13, 20
D 100 μ l	0, 0
D 400 μ l	0, 0
E 100 μ l	56, 70

Analysis of the colonies obtained

Miniprep DNA was prepared from 8 colonies of each of the Recombination reactions with primer sets A, B, or C. The supercoiled DNA obtained was analyzed on a 1% agarose gel: all eight of colonies from the

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recombination products of primer sets A and B were of the predicted size (2791 bp) for correct recombination between the PCR products (about 824 bp) and the attB1--ori--kan^r--attB3 sequence donated by pEYC 7102 (1967 bp). Three of the eight reaction products of primer set C were of the predicted size; the other five all were slightly larger than 4 kb.

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Further analysis of the reaction products was performed using two different restriction enzymes, *Ava*I and *Pvu*II, each of which cleaves twice (but at different locations) within the predicted recombinant product, once within the PCR product sequence and once within the sequence contributed by pEYC7102. Both of these enzymes should cleave the intact pEYC7102 recombination partner plasmid at two sites, to give fragments easily distinguished from those of the expected recombination products.

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The two restriction enzyme digests yielded the expected sizes of fragments (2373 and 430 bp for *Ava*I; 2473 and 330 bp for *Pvu*II) from the colonies generated from the recombination reactions with primer sets A and B, as well as for the three colonies from primer set C that displayed the expected size of supercoiled DNA. For the other five colonies from primer set C that yielded larger SC DNA, however, the *Pvu*II digest revealed fragments of approximate size to those predicted from a digestion of pEYC7102, whereas the *Ava*I digest revealed only a single fragment, approximately the size of linearized pEYC7102 (4161 bp).

Analysis

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These results indicate that PCR products generated from templates containing a gene flanked by attB sites can serve as efficient substrates for the reverse recombination reaction. The addition of even short DNA sequences to the ends of the attB1 and attB3 sites or core regions (e.g., 5bp and 8bp, respectively, in primer set B) stimulated this reaction by 100 fold or more. Surprisingly, reverse recombination reactions with PCR products containing additional sequence beyond the attB sites appeared in these reactions to be more efficient recombination partners than the supercoiled positive control plasmid, pEYC7501.

All the recombination products were generated faithfully. A low level of background colonies emerged from the relatively inefficient recombination reactions with primer set C, which lacked additional sequence beyond the 25 bp attB sites. This background appeared to be due to a largely intact pEZC7102 (which encodes kanamycin resistance) lacking an active ccdB death gene, allowing it to survive. Consistent with this interpretation is that one of the two restriction sites for Aval in this plasmid was also altered. One of the Aval sites is present within the ccdB region of pEZC7102. It is likely therefore that the alteration of this site was secondary to mutational inactivation of the ccdB gene.

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Example 11: Further Cloning of PCR Fragments

Two sets of 6 primers for preparing PCR products from the plasmid pBR322 as template were used. One set (Table 11) anneals to sequences flanking the *TetR* gene, including the *TetR* promoter. The other set (Table 12) anneals to sequences flanking the *AmpR* gene, including its promoter. The "tet" and "amp" primers used contain no attB sequences, only sequences inherent to the pBR322 plasmid; the "attB" primers contain, in addition to the pBR322 sequences, the 25 bp of attB 1 or attB3 sequences; the "attB+4" primers contain the pBR322-specific sequences, plus the 25 bp attB 1 or attB3 sequences, each with four Gs at the outer end. (Here "outer" refers to the end of the attB sequence not adjacent to the template-specific primer sequence.)

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Preparation of pBR322 template

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To improve the efficiency of the PCR reaction, the supercoiled pBR322 DNA was linearized by incubating 3.5 µg of Supercoiled (SC) pBR322 DNA in a 200 µl reaction with 15 units of the restriction enzyme NdeI and final concentration of 50mM Tris-HCl, pH8.0, 10mM MgCl₂, and 50mM NaCl, for one hour at 37°C.

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The digested pBR322 DNA was extracted once with phenol, isoamyl alcohol, and chloroform, extracted twice with isobutanol, and precipitated by adding two volumes of ethanol plus 0.15M sodium acetate. The precipitate was

washed once with 100% ethanol, dried, then dissolved in TE buffer. Recovery of DNA, quantitated on a 1 % agarose gel in TAE buffer, 0.5 µg/ml ethidium bromide, was estimated as greater than 80%.

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Table 11

tet Primer		Primer Sequence	SEQ ID NO:
tet-L		AAT TCT CAT GTT TGA CAG CTT ATC	48
tet-R		CGA TGG ATA TGT TCT GCC AAG	49
attB1-tetL		ACAAG TTTGTA CAAAAA AGCA GGCT- AAT TCT CAT GTT TGA CAG CTT ATC	50
attB3-tetR		ACCAC TTTGTA CAAGAA AGCT GGGT- CGA TGG ATA TGT TCT GCC AAG	51
attB1+4-tetL		GGGG ACAAG TTTGTA CAAAAA AGCA- GGCT AAT TCT CAT GTT TGA CAG CTT- ATC	52
attB3+4-tetR		GGGG ACCAC TTTGTA CAAGAA AGCT- GGGT CGA TGG ATA TGT TCT GCC AAG	53

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Table 12

amp Primer		Primer Sequence	SEQ ID NO:
amp-L		AAT ACA TTC AAA TAT GTA TCC GC	54
amp-R		TTA CCA ATG CTT AAT CAG TGA G	55
attB1-ampL		ACAAG TTTGTA CAAAAA AGCA GGCT - AAT ACA TTC AAA TAT GTA TCC GC	56
attB3-ampR		ACCAC TTTGTA CAAGAA AGCT GGGT- TTA CCA ATG CTT AAT CAG TGA G	57
attB1+4-ampL		GGGG ACAAG TTTGTA CAAAAA AGCA- GGCT AAT ACA TTC AAA TAT GTA TCC- GC	58
attB3+4-ampR		GGGG ACCAC TTTGTA CAAGAA AGCT- GGGT TTA CCA ATG CTT AAT CAG TGAG	59

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PCR amplification of tet and amp gene sequences

Six PCR reactions were performed, in 100 µl, consisting of 20mM Tris-HCl, pH 8.4, 50mM KC1, 1.5 mM MgCl₂, 0.2mM dNTPs, 2 ng linearized pBR322, 2.5 units of Taq DNA polymerase (GIBCO-BRL), and 0.5 uM of each pair of PCR primers listed in Tables 3 and 4. The reactions were first heated to 94 °C for 3'; then subjected to 25 cycles of 94 °C for 45 seconds, 55 °C for 30 seconds, and 72 °C for 1 minute. Based on 1% agarose gel analysis, all the reactions generated products of the expected size, in reasonable yields.

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Purification of PCR products

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The products from duplicate reactions were pooled; extracted with an equal volume of phenol, isoamyl alcohol, and chloroform; extracted twice with an equal volume of isobutanol; and precipitated with two volumes of ethanol, as above. The six precipitates were washed once with 100% ethanol, dried and dissolved in 100 µl TE. 1 µl aliquots were taken for gel analysis of the product before PEG precipitation.

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To each tube was added 50 µl of 30% PEG 8000, 30 mM MgCl₂. The solution was mixed well and centrifuged at 13,000 rpm for 10', at room temperature. The supernatant was carefully removed, and the precipitate dissolved in 100 µl TE. Recovery was quantitated on a 1% agarose and estimated to be over 90%. The gel analysis also revealed that nucleic acid products smaller than about 300 nucleotides had been effectively removed by the PEG precipitation step.

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Recombination Reactions

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Seven recombination reactions were performed, each in a total volume of 8 µl, containing 1 X integrase buffer, 40 ng pEYC7102 (Figure 11A), and 2 µl recombinase mixture (see above, Example 10). Each of the reactions also contained approximately 40 ng of one of the six above PCR products or, as a positive control, 40 ng of pEYC7501 (Figure 11B). The amp and tet PCR products with attB sites at their termini are shown in Figures 12A and 12B. The

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reactions were incubated at 25°C for 45', at 70°C for 10', then held at 0-5°C for 1-2 hours until used to transform *E. coli*.

E. coli transformation with recombination reaction products

1 µl of each of the recombination reactions was transformed into Max Efficiency DH5 α in a 50 µl transformation reaction, and following expression in SOC medium, 1/5 (100 µl) and 4/5 (400 µl) of each reaction were plated on culture plates containing 50 µg/ml kanamycin. The plates were incubated overnight and colonies were counted. The number of colonies obtained from each set of duplicate reactions are displayed in Table 13:

Table 13

Recombination Reactions		No. Colonies
tet 100 (100 µl)		6, 10
tet 400 (400 µl)		27, 32
attB-tet 100		9, 6
attB-tet 400		27, 36
attB+4-tet 100		824, 1064
attB+4-tet 400		>2000, >4000
amp 100		7, 13
amp 400		59, 65
attB-amp 100		18, 22
attB-amp 400		66, 66
attB+4-amp 100		3020, 3540
attB+4-amp 400		>5000, >5000
pEZC7501 100		320, 394
pEZC7501 400		1188, 1400

Analysis of the colonies obtained

As a rapid phenotypic screen, 10 of the colonies from the tet EZC reactions and 33 of the colonies from the attB+4-tet EZC reactions were streaked onto an LB culture plate containing tetracycline (15 µg/ml). As a control for the potency of the tetracycline, 3 colonies of pUC19-transformed cells, lacking a *TetR* gene, were also streaked onto the plate. All colonies from the attB+4-tet EZC

reactions grew well; colonies from the *tet* EZC reactions grew only very slightly, and the pUC19 colonies grew not at all.

Analogous results were obtained by streaking colonies from the *amp* PCR reactions on culture plates containing ampicillin (100 μ g/ml). All 21 colonies generated from the attB+4-amp recombination reactions grew well, whereas only one of 13 colonies from the attB-amp reactions grew in the presence of ampicillin. No growth was seen with any of the 15 colonies from the recombination reaction with amp PCR products.

To characterize plasmid DNA, eight colonies generated from the six EZC reactions with PCR products were picked into LB broth containing 50 μ g/ml kanamycin and grown overnight at 37°C. Miniprep DNA was prepared from 0.9 ml of each culture, and the size of the supercoiled DNA was analyzed on a 1% agarose gel in TAE buffer containing 0.5 μ g/ml ethidium bromide. The results are displayed in Table 14. The predicted structures of the recombination products are shown in Figure 12C and 12D.

Table 14

Recombination Reactions	DNA	Predicted Size (bp)	Number with Predicted Size
tet	SC (supercoiled)	3386	0/8
attB-tet	SC	3386	1/8
attB+4-tet	SC AvaI+Bam	3386 485, 2901	7/7 3/3
amp	SC	2931	0/8
attB-amp	SC	2931	3/8
attB+4-amp	SC Pst	2931 429, 2502	8/8 3/3

Analysis

These results, based on the amplification of two different gene sequences, tet and amp, within the plasmid pBR322 clearly demonstrate that PCR products generated using primers containing the 25 bp attB1 and attB3 recombination sequence serve as highly efficient substrates for the recombination reaction. 5 Addition of a short sequence to the outside of each 25 bp attB site stimulates the recombination reaction by over 100 fold, as also observed in the experiments of Example 10. Also similar to Example 10, the efficiency of the recombination reactions using linear PCR products with attB sites exceeded the efficiency obtained with the positive control SC DNA plasmid, pEYC7501.

10 Further, a high percentage of the reaction products are as predicted, since all 33 colonies tested from the attB+4-tet reactions displayed functional tetracycline resistance, and all 21 of the colonies from the attB+4-amp reactions displayed ampicillin resistance. All 16 of the miniprep DNAs, examined from the recombination reactions of either attB+4-tet or attB+4-amp PCR products with 15 pEYC7102, generated supercoiled DNA and restriction digest fragments of the correct sizes.

Example 12: Use of Topoisomerase to Stimulate Recombination

20 The stimulation of the recombination reaction by making one or the parental plasmids linear was not expected. If the stimulation resulted from relief of some conformation constraint arising during the two recombination reactions (formation of the Cointegrate and resolution to the two daughter molecules), then 25 unwinding of the plasmids with a topoisomerase might also be stimulatory when one or both parental plasmids were circular.

The Insert Donor was pEYC2901 (Figure 7A), and the Vector Donor was pEYC3101 (Figure 7B). A portion of pEYC3101 was linearized with Mlu I. 20 ng of pEYC2901 and/or pEYC3101 were used in each 10 μ l reaction (29 ng Int, 30 2.9 ng Xis, 5.4 ng IHF in 50 mM Tris HCl pH about 7.8, 16.5 mM NaCl, 35 mM KCl, 5 mM spermidine, 0.375 mg/ml BSA, 0.25 mM EDTA, 2% glycerol).

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Topoisomerase I (from calf Thymus; Life Technologies, Inc.) was diluted from 15 units/ μ l to the concentrations indicated in Table 15 in 1 X EZC buffer.

Table 15

	1	2	3	4	5	6	7	8	9	10
Circular 3101						2	2	2	2	2
Linear 3101	2	2	2	2	2					
Circular 2901		2	2	2	2		2	2	2	2
Recombinase	2	2	2	2	2	2	2	2	2	2
TE	2					2				
Topoisomerase, 1:60			2					2		
Topoisomerase, 1:20				2					2	
Topoisomerase, 1:6					2					2
3 X Buffer	2	2	2	2	2	2	2	2	2	2
1 X Buffer	2	2				2	2			

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These reactions were assembled in the following order: buffer; TE; DNAs; Clonase; Topoisomerase. The reactions were incubated at 22° - 28° for 45 minutes, then at 70° for 5 minutes. 1 μ l aliquots were transformed into UltraMax DH5 α competent *E. coli* (Life Technologies, Inc.). Following expression, aliquots were plated on 100 μ g/ml kanamycin and incubated at 30° for 48 hours. Results: see Table 16.

Table 16

Reaction #	Colonies	Vector Donor	Insert Donor	Recombinase	Topoisomerase
1	0	linear 3101	--	+	--
2	245	linear 3101	circular 2901	+	--
3	221	linear 3101	circular 2901	+	0.5 units
4	290	linear 3101	circular 2901	+	1.6 units
5	355	linear 3101	circular 2901	+	5 units
6	0	circular 3101		+	--
7	23	circular 3101	circular 2901	+	--
8	209	circular 3101	circular 2901	+	0.5 units
9	119	circular 3101	circular 2901	+	1.6 units
10	195	circular 3101	circular 2901	+	5 units

Analysis

Linearizing the Vector Donor increased the number of colonies about 10 fold (reaction 2 vs. reaction 7). Addition of 0.5 to 5 units of topoisomerase I to reactions containing circular Insert Donor and linear Vector Donor had little or no effect on the number of colonies (reaction 2 compared to reactions 3, 4, and 5; maximum 1.4 fold). In contrast, if both parental plasmids were circular (reaction 7 -10), the addition of topoisomerase stimulated the number of colonies 5 to 9 fold. Thus addition of topoisomerase I to reactions in which both parental plasmids were circular stimulated the recombination reactions nearly as much as linearizing the Vector Donor parent. Topoisomerase I was active when used in combination with the three recombination proteins, in recombination buffer. The addition of topoisomerase I to the recombination reaction relieves the necessity to linearize the Vector Donor to achieve stimulation of the recombination reactions.

Having now fully described the present invention in some detail by way of illustration and example for purposes of clarity of understanding, it will be obvious to one of ordinary skill in the art that the same can be performed by modifying or changing the invention within a wide and equivalent range of conditions, formulations and other parameters without affecting the scope of the invention or any specific embodiment thereof, and that such modifications or changes are intended to be encompassed within the scope of the appended claims.

All publications, patents and patent applications mentioned in this specification are indicative of the level of skill of those skilled in the art to which this invention pertains, and are herein incorporated by reference to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference.

Applicant's or agent's file reference number 0942.285PC04	International application No. TO BE ASSIGNED
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INDICATIONS RELATING TO A DEPOSITED MICROORGANISM
(PCT Rule 13bis)

A. The indications made below relate to the microorganism referred to in the description on pages 35 line 31 and 36 line 1.	
B. IDENTIFICATION OF DEPOSIT	
Name of depository institution Agricultural Research Culture Collection (NRRL)	
Address of depository institution (<i>including postal code and country</i>) 1815 N. University Street Peoria, Illinois 61604 United States of America	
Date of deposit October 14, 1997	Accession Number NRRL B-21852
C. ADDITIONAL INDICATIONS (<i>leave blank if not applicable</i>)	
This information is continued on an additional sheet <input type="checkbox"/>	
D. DESIGNATED STATES FOR WHICH INDICATIONS ARE MADE (<i>if the indications are not for all designated States</i>)	
E. SEPARATE FURNISHING OF INDICATIONS (<i>leave blank if not applicable</i>)	
The indications listed below will be submitted to the international Bureau later (<i>specify the general nature of the indications, e.g., "Accession Number of Deposit"</i>)	

For receiving Office use only		For International Bureau use only	
<input checked="" type="checkbox"/> This sheet was received with the international application		<input type="checkbox"/> This sheet was received by the International Bureau on:	
Authorized officer		Authorized officer	
			

WHAT IS CLAIMED IS:

1. A method for cloning or subcloning one or more desired nucleic acid molecules comprising
 - 5 (a) combining *in vitro* or *in vivo*
 - (i) one or more Insert Donor molecules comprising one or more desired nucleic acid segments flanked by at least two recombination sites, wherein said recombination sites do not substantially recombine with each other;
 - (ii) one or more Vector Donor molecules comprising at least two recombination sites, wherein said recombination sites do not substantially recombine with each other; and
 - (iii) one or more site-specific recombination proteins;
 - (b) incubating said combination under conditions sufficient to transfer one or more of said desired segments into one or more of said Vector Donor molecules, thereby producing one or more desired Product nucleic acid molecules;
 - (c) combining *in vitro* or *in vivo*
 - (i) one or more of said Product molecules comprising said desired segments flanked by two or more recombination sites, wherein said recombination sites do not substantially recombine with each other;
 - (ii) one or more different Vector Donor molecules comprising two or more recombination sites, wherein said recombination sites do not substantially recombine with each other; and
 - (iii) one or more site-specific recombination proteins; and
 - (d) incubating said combination under conditions sufficient to transfer one or more of said desired segments into one or more different Vector Donor molecules, thereby producing one or more different Product molecules.

2. The method of claim 1, further comprising incubating said different Product molecules with one or more different Vector Donor molecules under conditions sufficient to transfer one or more of said desired segments into said different Vector Donor molecules.

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3. A method for cloning or subcloning desired nucleic acid molecules comprising

a) combining *in vitro* or *in vivo*

i) one or more Insert Donor molecules comprising one or more nucleic acid segments flanked by two or more recombination sites, wherein said recombination sites do not substantially recombine with each other;

10 ii) two or more different Vector Donor molecules comprising two or more recombination sites, wherein said recombination sites do not substantially recombine with each other; and

15 iii) one or more site specific recombination proteins; and

b) incubating said combination under conditions sufficient to transfer one or more of said desired segments into said different Vector Donor molecules, thereby producing two or more different Product molecules.

20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 1240 1245 1250 1255 1260 1265 1270 1275 1280 1285 1290 1295 1300 1305 1310 1315 1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415 1420 1425 1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 1525 1530 1535 1540 1545 1550 1555 1560 1565 1570 1575 1580 1585 1590 1595 1600 1605 1610 1615 1620 1625 1630 1635 1640 1645 1650 1655 1660 1665 1670 1675 1680 1685 1690 1695 1700 1705 1710 1715 1720 1725 1730 1735 1740 1745 1750 1755 1760 1765 1770 1775 1780 1785 1790 1795 1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100 2105 2110 2115 2120 2125 2130 2135 2140 2145 2150 2155 2160 2165 2170 2175 2180 2185 2190 2195 2200 2205 2210 2215 2220 2225 2230 2235 2240 2245 2250 2255 2260 2265 2270 2275 2280 2285 2290 2295 2300 2305 2310 2315 2320 2325 2330 2335 2340 2345 2350 2355 2360 2365 2370 2375 2380 2385 2390 2395 2400 2405 2410 2415 2420 2425 2430 2435 2440 2445 2450 2455 2460 2465 2470 2475 2480 2485 2490 2495 2500 2505 2510 2515 2520 2525 2530 2535 2540 2545 2550 2555 2560 2565 2570 2575 2580 2585 2590 2595 2600 2605 2610 2615 2620 2625 2630 2635 2640 2645 2650 2655 2660 2665 2670 2675 2680 2685 2690 2695 2700 2705 2710 2715 2720 2725 2730 2735 2740 2745 2750 2755 2760 2765 2770 2775 2780 2785 2790 2795 2800 2805 2810 2815 2820 2825 2830 2835 2840 2845 2850 2855 2860 2865 2870 2875 2880 2885 2890 2895 2900 2905 2910 2915 2920 2925 2930 2935 2940 2945 2950 2955 2960 2965 2970 2975 2980 2985 2990 2995 3000 3005 3010 3015 3020 3025 3030 3035 3040 3045 3050 3055 3060 3065 3070 3075 3080 3085 3090 3095 3100 3105 3110 3115 3120 3125 3130 3135 3140 3145 3150 3155 3160 3165 3170 3175 3180 3185 3190 3195 3200 3205 3210 3215 3220 3225 3230 3235 3240 3245 3250 3255 3260 3265 3270 3275 3280 3285 3290 3295 3300 3305 3310 3315 3320 3325 3330 3335 3340 3345 3350 3355 3360 3365 3370 3375 3380 3385 3390 3395 3400 3405 3410 3415 3420 3425 3430 3435 3440 3445 3450 3455 3460 3465 3470 3475 3480 3485 3490 3495 3500 3505 3510 3515 3520 3525 3530 3535 3540 3545 3550 3555 3560 3565 3570 3575 3580 3585 3590 3595 3600 3605 3610 3615 3620 3625 3630 3635 3640 3645 3650 3655 3660 3665 3670 3675 3680 3685 3690 3695 3700 3705 3710 3715 3720 3725 3730 3735 3740 3745 3750 3755 3760 3765 3770 3775 3780 3785 3790 3795 3800 3805 3810 3815 3820 3825 3830 3835 3840 3845 3850 3855 3860 3865 3870 3875 3880 3885 3890 3895 3900 3905 3910 3915 3920 3925 3930 3935 3940 3945 3950 3955 3960 3965 3970 3975 3980 3985 3990 3995 4000 4005 4010 4015 4020 4025 4030 4035 4040 4045 4050 4055 4060 4065 4070 4075 4080 4085 4090 4095 4100 4105 4110 4115 4120 4125 4130 4135 4140 4145 4150 4155 4160 4165 4170 4175 4180 4185 4190 4195 4200 4205 4210 4215 4220 4225 4230 4235 4240 4245 4250 4255 4260 4265 4270 4275 4280 4285 4290 4295 4300 4305 4310 4315 4320 4325 4330 4335 4340 4345 4350 4355 4360 4365 4370 4375 4380 4385 4390 4395 4400 4405 4410 4415 4420 4425 4430 4435 4440 4445 4450 4455 4460 4465 4470 4475 4480 4485 4490 4495 4500 4505 4510 4515 4520 4525 4530 4535 4540 4545 4550 4555 4560 4565 4570 4575 4580 4585 4590 4595 4600 4605 4610 4615 4620 4625 4630 4635 4640 4645 4650 4655 4660 4665 4670 4675 4680 4685 4690 4695 4700 4705 4710 4715 4720 4725 4730 4735 4740 4745 4750 4755 4760 4765 4770 4775 4780 4785 4790 4795 4800 4805 4810 4815 4820 4825 4830 4835 4840 4845 4850 4855 4860 4865 4870 4875 4880 4885 4890 4895 4900 4905 4910 4915 4920 4925 4930 4935 4940 4945 4950 4955 4960 4965 4970 4975 4980 4985 4990 4995 5000 5005 5010 5015 5020 5025 5030 5035 5040 5045 5050 5055 5060 5065 5070 5075 5080 5085 5090 5095 5100 5105 5110 5115 5120 5125 5130 5135 5140 5145 5150 5155 5160 5165 5170 5175 5180 5185 5190 5195 5200 5205 5210 5215 5220 5225 5230 5235 5240 5245 5250 5255 5260 5265 5270 5275 5280 5285 5290 5295 5300 5305 5310 5315 5320 5325 5330 5335 5340 5345 5350 5355 5360 5365 5370 5375 5380 5385 5390 5395 5400 5405 5410 5415 5420 5425 5430 5435 5440 5445 5450 5455 5460 5465 5470 5475 5480 5485 5490 5495 5500 5505 5510 5515 5520 5525 5530 5535 5540 5545 5550 5555 5560 5565 5570 5575 5580 5585 5590 5595 5600 5605 5610 5615 5620 5625 5630 5635 5640 5645 5650 5655 5660 5665 5670 5675 5680 5685 5690 5695 5700 5705 5710 5715 5720 5725 5730 5735 5740 5745 5750 5755 5760 5765 5770 5775 5780 5785 5790 5795 5800 5805 5810 5815 5820 5825 5830 5835 5840 5845 5850 5855 5860 5865 5870 5875 5880 5885 5890 5895 5900 5905 5910 5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965 5970 5975 5980 5985 5990 5995 6000 6005 6010 6015 6020 6025 6030 6035 6040 6045 6050 6055 6060 6065 6070 6075 6080 6085 6090 6095 6100 6105 6110 6115 6120 6125 6130 6135 6140 6145 6150 6155 6160 6165 6170 6175 6180 6185 6190 6195 6200 6205 6210 6215 6220 6225 6230 6235 6240 6245 6250 6255 6260 6265 6270 6275 6280 6285 6290 6295 6300 6305 6310 6315 6320 6325 6330 6335 6340 6345 6350 6355 6360 6365 6370 6375 6380 6385 6390 6395 6400 6405 6410 6415 6420 6425 6430 6435 6440 6445 6450 6455 6460 6465 6470 6475 6480 6485 6490 6495 6500 6505 6510 6515 6520 6525 6530 6535 6540 6545 6550 6555 6560 6565 6570 6575 6580 6585 6590 6595 6600 6605 6610 6615 6620 6625 6630 6635 6640 6645 6650 6655 6660 6665 6670 6675 6680 6685 6690 6695 6700 6705 6710 6715 6720 6725 6730 6735 6740 6745 6750 6755 6760 6765 6770 6775 6780 6785 6790 6795 6800 6805 6810 6815 6820 6825 6830 6835 6840 6845 6850 6855 6860 6865 6870 6875 6880 6885 6890 6895 6900 6905 6910 6915 6920 6925 6930 6935 6940 6945 6950 6955 6960 6965 6970 6975 6980 6985 6990 6995 7000 7005 7010 7015 7020 7025 7030 7035 7040 7045 7050 7055 7060 7065 7070 7075 7080 7085 7090 7095 7100 7105 7110 7115 7120 7125 7130 7135 7140 7145 7150 7155 7160 7165 7170 7175 7180 7185 7190 7195 7200 7205 7210 7215 7220 7225 7230 7235 7240 7245 7250 7255 7260 7265 7270 7275 7280 7285 7290 7295 7300 7305 7310 7315 7320 7325 7330 7335 7340 7345 7350 7355 7360 7365 7370 7375 7380 7385 7390 7395 7400 7405 7410 7415 7420 7425 7430 7435 7440 7445 7450 7455 7460 7465 7470 7475 7480 7485 7490 7495 7500 7505 7510 7515 7520 7525 7530 7535 7540 7545 7550 7555 7560 7565 7570 7575 7580 7585 7590 7595 7600 7605 7610 7615 7620 7625 7630 7635 7640 7645 7650 7655 7660 7665 7670 7675 7680 7685 7690 7695 7700 7705 7710 7715 7720 7725 7730 7735 7740 7745 7750 7755 7760 7765 7770 7775 7780 7785 7790 7795 7800 7805 7810 7815 7820 7825 7830 7835 7840 7845 7850 7855 7860 7865 7870 7875 7880 7885 7890 7895 7900 7905 7910 7915 7920 7925 7930 7935 7940 7945 7950 7955 7960 7965 7970 7975 7980 7985 7990 7995 8000 8005 8010 8015 8020 8025 8030 8035 8040 8045 8050 8055 8060 8065 8070 8075 8080 8085 8090 8095 8100 8105 8110 8115 8120 8125 8130 8135 8140 8145 8150 8155 8160 8165 8170 8175 8180 8185 8190 8195 8200 8205 8210 8215 8220 8225 8230 8235 8240 8245 8250 8255 8260 8265 8270 8275 8280 8285 8290 8295 8300 8305 8310 8315 8320 8325 8330 8335 8340 8345 8350 8355 8360 8365 8370 8375 8380 8385 8390 8395 8400 8405 8410 8415 8420 8425 8430 8435 8440 8445 8450 8455 8460 8465 8470 8475 8480 8485 8490 8495 8500 8505 8510 8515 8520 8525 8530 8535 8540 8545 8550 8555 8560 8565 8570 8575 8580 8585 8590 8595 8600 8605 8610 8615 8620 8625 8630 8635 8640 8645 8650 8655 8660 8665 8670 8675 8680 8685 8690 8695 8700 8705 8710 8715 8720 8725 8730 8735 8740 8745 8750 8755 8760 8765 8770 8775 8780 8785 8790 8795 8800 8805 8810 8815 8820 8825 8830 8835 8840 8845 8850 8855 8860 8865 8870 8875 8880 8885 8890 8895 8900 8905 8910 8915 8920 8925 8930 8935 8940 8945 8950 8955 8960 8965 8970 8975 8980 8985 8990 8995 9000 9005 9010 9015 9020 9025 9030 9035 9040 9045 9050 9055 9060 9065 9070 9075 9080 9085 9090 9095 9100 9105 9110 9115 9120 9125 9130 9135 9140 9145 9150 9155 9160 9165 9170 9175 9180 9185 9190 9195 9200 9205 9210 9215 9220 9225 9230 9235 9240 9245 9250 9255 9260 9265 9270 9275 9280 9285 9290 9295 9300 9305 9310 9315 9320 9325 9330 9335 9340 9345 9350 9355 9360 9365 9370 9375 9380 9385 9390 9395 9400 9405 9410 9415 9420 9425 9430 9435 9440 9445 9450 9455 9460 9465 9470 9475 9480 9485 9490 9495 9500 9505 9510 9515 9520 9525 9530 9535 9540 9545 9550 9555 9560 9565 9570 9575 9580 9585 9590 9595 9600 9605 9610 9615 9620 9625 9630 9635 9640 9645 9650 9655 9660 9665 9670 9675 9680 9685 9690 9695 9700 9705 9710 9715 9720 9725 9730 9735 9740 9745 9750 9755 9760 9765 9770 9775 9780 9785 9790 9795 9800 9805 9810 9815 9820 9825 9830 9835 9840 9845 9850 9855 9860 9865 9870 9875 9880 9885 9890 9895 9900 9905 9910 9915 9920 9925 9930 9935 9940 9945 9950 9955 9960 9965 9970 9975 9980 9985 9990 9995 9999 10000 10005 10010 10015 10020 10025 10030 10035 10040 10045 10050 10055 10060 10065 10070 10075 10080 10085 10090 10095 100100 100105 100110 100115 100120 100125 100130 100135 100140 100145 100150 100155 100160 100165 100170 100175 100180 100185 100190 100195 100200 100205 100210 100215 100220 100225 100230 100235 100240 100245 100250 100255 100260 100265 100270 100275 100280 100285 100290 100295 100300 100305 100310 100315 100320 100325 100330 100335 100340 100345 100350 100355 100360 100365 100370 100375 100380 100385 100390 100395 100400 100405 100410 100415 100420 100425 100430 100435 100440 100445 100450 100455 100460 100465 100470 100475 100480 100485 100490 100495 100500 100505 100510 100515 100520 100525 100530 100535 100540 100545 100550 100555 100560 100565 100570 100575 100580 100585 100590 100595 100600 100605 100610 100615 100620 100625 100630 100635 100640 100645 100650 100655 100660 100665 100670 100675 100680 100685 100690 100695 100700 100705 100710 100715 100720 100725 100730 100735 10074

7. The method of claim 1 or claim 3, wherein said Vector Donor molecules comprise at least one Selectable marker.

8. The method of claim 7, wherein the Selectable marker comprises at least one DNA segment selected from the group consisting of:

- (a) a DNA segment that encodes a product that provides resistance in a recipient cell against otherwise toxic compounds;
- (b) a DNA segment that encodes a product that is otherwise lacking in a recipient cell;
- 5 (c) a DNA segment that encodes a product that suppresses the activity of a gene product in a recipient cell;
- (d) a DNA segment that encodes a product that can be identified;
- (e) a DNA segment that encodes a product that inhibits a cell function in a recipient cell;
- 10 (f) a DNA segment that inhibits the activity of any of the DNA segments of (a)-(e) above;
- (g) a DNA segment that binds a product that modifies a substrate;
- (h) a DNA segment that encodes a specific nucleotide recognition sequence which can be recognized by a protein, an RNA, DNA or chemical.
- 15 (i) a DNA segment that, when deleted, directly or indirectly confers sensitivity to cell killing by particular compounds within a recipient cell;
- (j) a DNA segment that encodes a product that is toxic in a recipient cell; and
- 20 (k) a DNA segment that can be used to isolate or identify a desired molecule.

9. The method of claim 8, wherein said Selectable marker comprises at least one marker selected from the group consisting of an antibiotic resistance gene, a tRNA gene, an auxotrophic marker, a toxic gene, a phenotypic marker, an antisense oligonucleotide, a restriction endonuclease, a restriction endonuclease

cleavage site, an enzyme cleavage site, a protein binding site, and a sequence complementary to a PCR primer sequence.

5 10. The method of claim 1 or claim 3, wherein said Vector Donor

molecules comprise prokaryotic and/or eukaryotic vectors.

11. The method of claim 10, wherein said eukaryotic vectors comprise vectors which propagate and/or replicate in yeast cells, plant cells, fish cells, eukaryotic cells, mammalian cells, and/or insect cells.

10

12. The method of claim 10, wherein said prokaryotic vectors comprise vectors which propagate and/or replicate in gram negative or gram positive bacteria.

15

13. The method of claim 12, wherein said prokaryotic vectors comprise vectors which propagate and/or replicate in bacteria of the genus *Escherichia*, *Salmonella*, *Bacillus*, *Streptomyces* and/or *Pseudomonas*.

20

14. The method of claim 13, wherein said prokaryotic vector comprises a vector which propagates and/or replicates in *E. coli*.

25

15. The method of claim 10, wherein said Vector Donor molecules are selected from the group consisting of cloning vectors, sequencing vectors, expression vectors, fusion vectors, 2-hybrid vectors, reverse 2-hybrid vectors or derivatives or variants thereof.

30

16. The method of claim 10, wherein said eukaryotic vectors are selected from the group consisting of pFastBac, pFastBac HT, pFastBac DUAL, pSFV, pTet-Splice, pEUK-C1, pPUR, pMAM, pMAMneo, pBI101, pBI121, pDR2, pCMVEBNA, YACneo, pSVK3, pSVL, pMSG, pCH110, pKK232-8, p3'SS, pXT1, pSG5, pPbac, pMbac, pMC1neo, and pOG44, pYES2, pAC360,

pBlueBacHis, pVL1392, pBlueBacIII, pCDM8, pcDNA1, pZeoSV, pcDNA3 pREP4, pCEP4, and pEBVHis or derivatives or variants thereof.

17. The method of claim 10, wherein said prokaryotic vectors are selected from the group consisting of pcDNA II, pSL301, pSE280, pSE380, pSE420, pTrcHis, pRSET, pGEMEX-1, pGEMEX-2, pET, pTrc99A, pKK223-3, pGEX, pEZ218, pRIT2T, pMC1871, pKK233-2, pKK388-1, and pProEx-HT or derivatives or variants thereof.

10 18. The method of claim 15, wherein said 2-hybrid and reverse 2-hybrid vectors are selected from the group consisting of pPC86, pDBLeu, pDBTrp, pPC97, p2.5, pGAD1-3, pGAD10, pACt, pACT2, pGADGL, pGADGH, pAS2-1, pGAD424, pGBT8, pGBT9, pGAD-GAL4, pLexA, pBD-GAL4, pHISi, pHISi-1, placZi, pB42AD, pDG202, pJK202, pJG4-5, pNLexA, 15 and pYESTrp or derivatives or variants thereof.

19. The method of claim 1 or claim 3, wherein said Insert Donor molecules comprise a vector.

20 20. The method of claim 1 or claim 3, wherein said Insert Donor molecules comprise a DNA segment produced by amplification.

21. The method of claim 20, wherein said amplification is PCR.

25 22. The method of claim 21, wherein said Insert Donor is linear.

23. The method of claim 22, wherein said Insert Donor comprises at least one recombination site at or near one or both termini of said linear molecule.

30 24. The method of claim 1 or claim 3, wherein said recombination sites are selected from the group consisting of loxP, attB, attP, attL, and attR.

25. The method of claim 1 or claim 3, wherein said recombination proteins are selected from the group consisting of Int, Cre, Flp, Res.

5 26. A method for preparing a nucleic acid molecule comprising two or more recombination sites or portions thereof comprising

- (a) mixing a nucleic acid template with a polypeptide having polymerase activity and one or more primers comprising one or more recombination sites or portions thereof; and
- (b) incubating said mixture under conditions sufficient to synthesize a nucleic acid molecule which is complementary to all or a portion of said template and which comprises one or more recombination sites or portions thereof.

10 27. The method of claim 26, further comprising incubating said synthesized molecule in the presence of one or more primers comprising one or more recombination sites or portions thereof under conditions sufficient to synthesize a second nucleic acid molecule complementary to all or a portion to said first nucleic acid molecule, thereby producing a double stranded nucleic acid molecule comprising two or more recombination sites or portions thereof.

20 28. The method of claim 27, wherein said recombination sites or portions thereof are located at or near one or more termini of said synthesized double stranded nucleic acid molecule.

25 29. The method of claim 27, wherein said template is RNA or DNA.

30. The method of claim 29, wherein said RNA is an mRNA or a polyA RNA molecule.

30 31. The method of claim 27, wherein said polypeptide is selected from the group consisting of a reverse transcriptase or DNA polymerase.

32. The method of claim 31, wherein said DNA polymerase is a thermostable DNA polymerase.

33. The method of claim 32, wherein said thermostable DNA polymerase is selected from the group consisting of *Thermus thermophilus* (*Tth*) DNA polymerase, *Thermus aquaticus* (*Taq*) DNA polymerase, *Thermatoga neopolitana* (*Tne*) DNA polymerase, *Thermatoga maritima* (*Tma*) DNA polymerase, *Thermococcus litoralis* (*Tli* or VENT®) DNA polymerase, *Pyrococcus furiosus* (*Pfu* or DEEPVENT®) DNA polymerase, *Pyrococcus woosii* (*Pwo*) DNA polymerase, *Bacillus stearothermophilus* (*Bst*) DNA polymerase, *Sulfolobus acidocaldarius* (*Sac*) DNA polymerase, *Thermoplasma acidophilum* (*Tac*) DNA polymerase, *Thermus flavus* (*Tfl/Tub*) DNA polymerase, *Thermus ruber* (*Tru*) DNA polymerase, *Thermus brockianus* (DYNAZYME®) DNA polymerase, *Methanobacterium thermoautotrophicum* (*Mth*) DNA polymerase, and mutants, variants and derivatives thereof.

34. The method of claim 27, further comprising amplifying said first and second nucleic acid molecules.

35. The method of claim 34, wherein said amplification is accomplished by a method comprising

- (a) contacting said first nucleic acid molecule with a first primer which is complementary to a portion of said first nucleic acid molecule, and a second nucleic acid molecule with a second primer which is complementary to a portion of said second nucleic acid molecule with a polypeptide having polymerase activity;
- (b) incubating said mixture under conditions sufficient to form a third nucleic acid molecule complementary to all or a portion of said first nucleic acid molecule and a fourth nucleic acid molecule complementary to all or a portion of said second nucleic acid molecule;

(c) denaturing said first and third and said second and fourth nucleic acid molecules; and
(d) repeating steps (a) through (c) one or more times,
wherein said first primer and/or said second primer comprise one or more recombination sites or portions thereof.

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36. A method for amplifying a nucleic acid molecule comprising
(a) contacting a first nucleic acid molecule with a first primer which is complementary to a portion of said first nucleic acid molecule, and a second nucleic acid molecule with a second primer which is complementary to a portion of said second nucleic acid molecule with a polypeptide having polymerase activity;
(b) incubating said mixture under conditions sufficient to form a third nucleic acid molecule complementary to all or a portion of said first nucleic acid molecule and a fourth nucleic acid molecule complementary to all or portion of all or said portion of said second nucleic acid molecule;
(c) denaturing said first and third and said second and fourth nucleic acid molecule; and
(d) repeating steps (a) through (c) one or more times,
wherein said first primer and/or second primer comprise one or more recombination sites or portions thereof.

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37. A method for producing one or more cDNA molecules or a population of cDNA molecules comprising
(a) mixing an RNA template or population of RNA templates with a reverse transcriptase and one or more primers wherein said primers comprise one or more recombination sites or portions thereof; and
(b) incubating said mixture under conditions sufficient to make a first DNA molecule complementary to all or a portion of said template,

thereby forming a first DNA molecule comprising one or more recombination sites or portions thereof.

38. The method of claim 37, further comprising incubating said first DNA molecule with one or more primers which comprise one or more recombination sites or portions thereof under conditions sufficient to make a second DNA molecule complementary to all or a portion of said first DNA molecule, thereby producing a double stranded DNA molecule which comprises one or more recombination sites or portions thereof.

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39. The method of claim 38, wherein said double stranded DNA molecule is linear.

40. The method of claim 39, wherein said double stranded DNA molecule comprises one or more recombination sites or portions thereof at or near one or both termini of said double stranded DNA molecule.

41. A method for synthesizing one or more nucleic acid molecules comprising one or more recombination sites, said method comprising:

20 (a) obtaining one or more linear nucleic acid molecules; and
(b) contacting said molecules with one or more adapters which comprise one or more recombination sites or portions thereof under conditions sufficient to add one or more of said adapters to one or more termini of said linear nucleic acid molecule.

25

42. The method of claim 41, wherein said linear nucleic acid molecules are derived from genomic DNA.

30 43. The method of claim 41, wherein said linear nucleic acid molecules are derived from cDNA.

44. The method of claim 41, wherein said linear nucleic acid molecules are produced by mechanical or enzymatic techniques.

5 45. The method of claim 41, wherein said linear nucleic acid molecules are produced by digesting one or more nucleic acid molecules with one or more restriction endonucleases.

10 46. A method for adding one or more recombination sites or portions thereof to one or more nucleic acid molecules, said method comprising:

- (a) contacting one or more nucleic acid molecules with one or more integration sequences which comprise one or more recombination sites or portions thereof; and
- (b) incubating said mixture under conditions sufficient to incorporate said integration sequences into said nucleic acid molecules.

15 47. The method of claim 46, wherein said integration sequences are selected from the group consisting of transposons, integrating viruses, integrating elements, integrons and recombination sequences.

20 48. The method of claim 47, wherein said integration sequence is added to genomic DNA.

25 49. A product produced by the process of any one of claims 1, 3, 27, 37, 41, and 46.

50. The method of claim 1 or claim 3, wherein said segment is produced by chemical synthesis.

30 51. The method of claim 47, wherein said integration sequence is added to a vector.

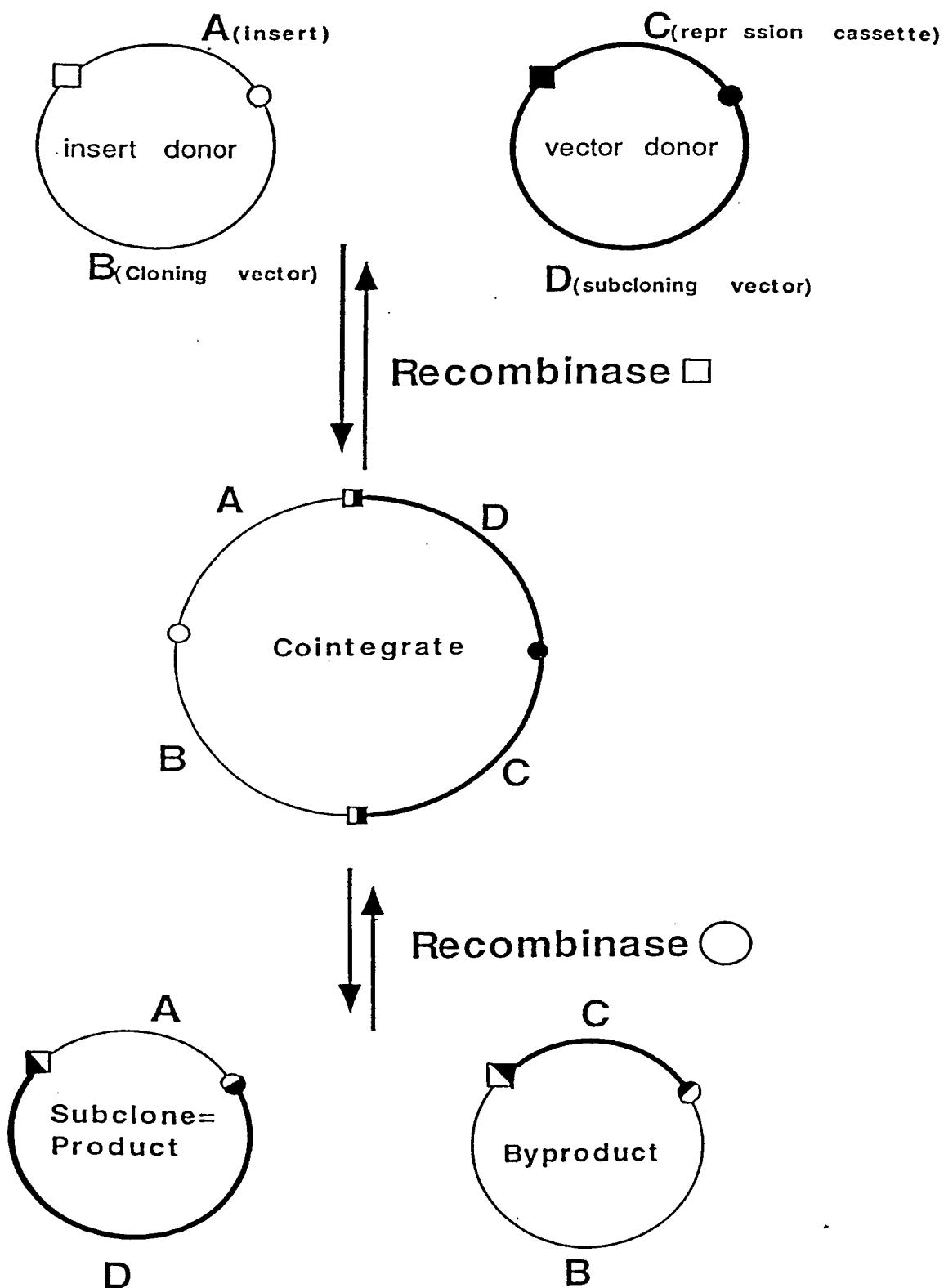
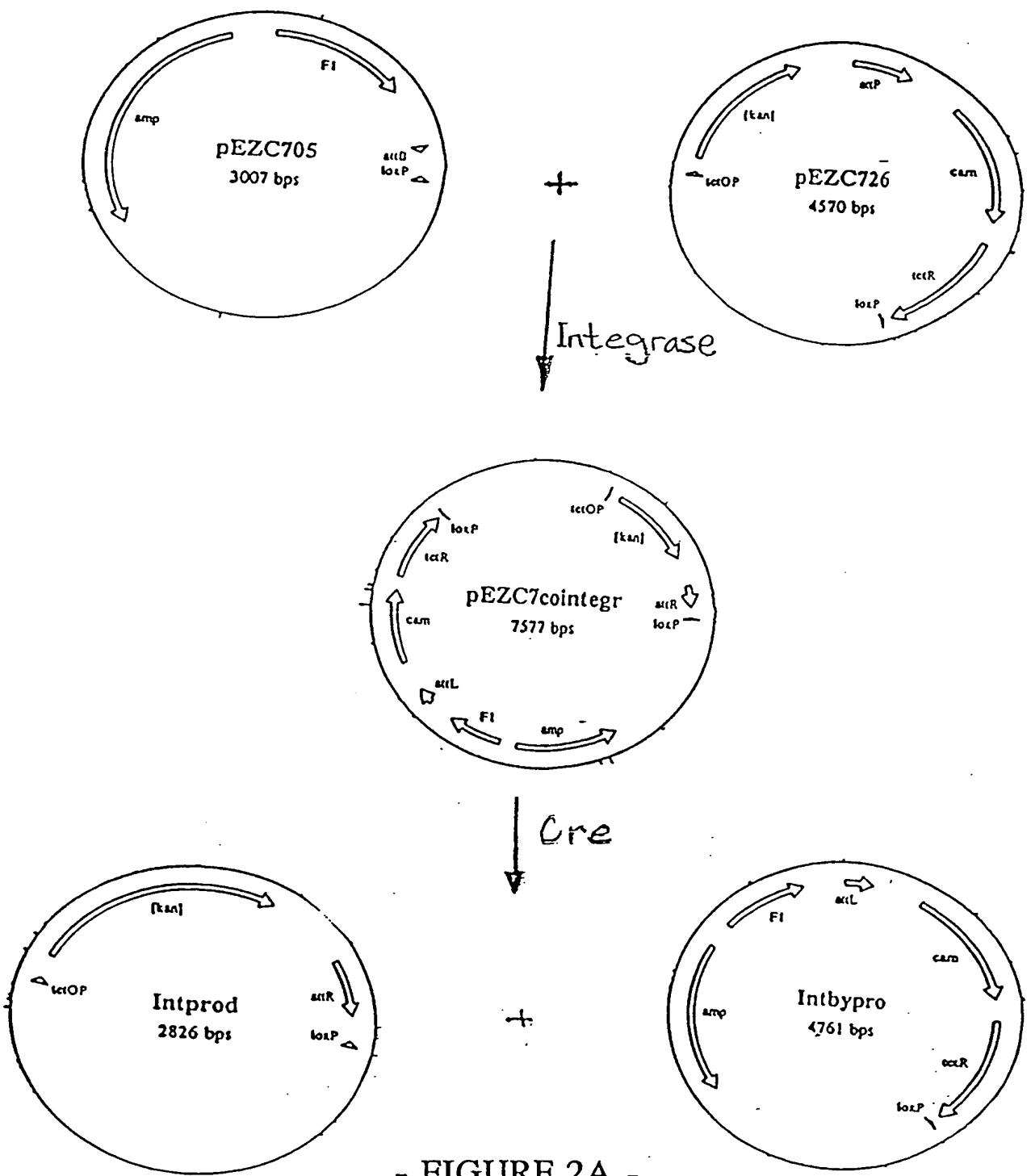
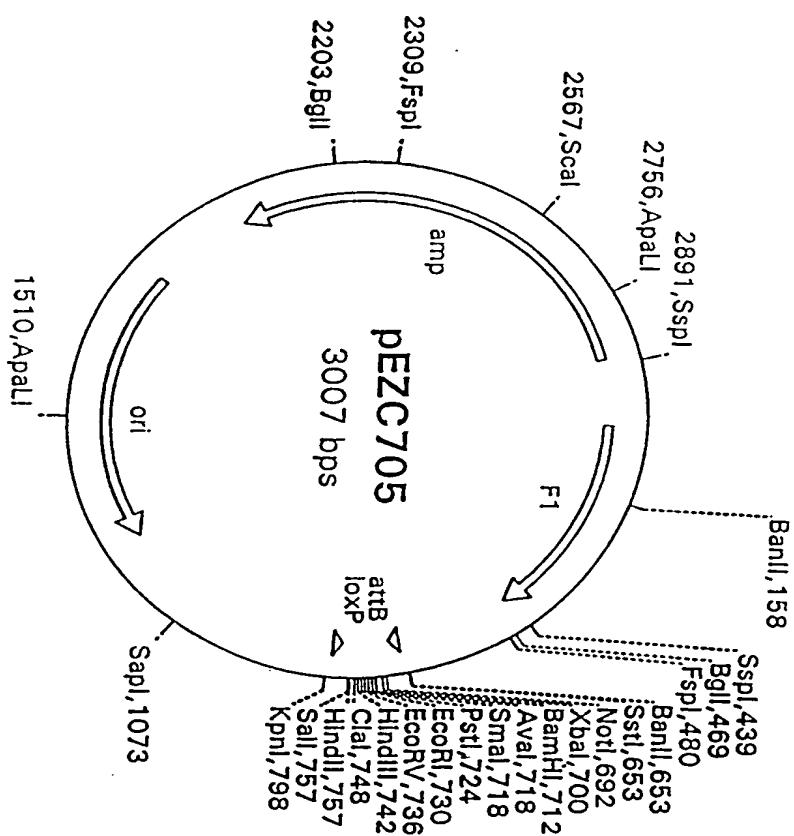


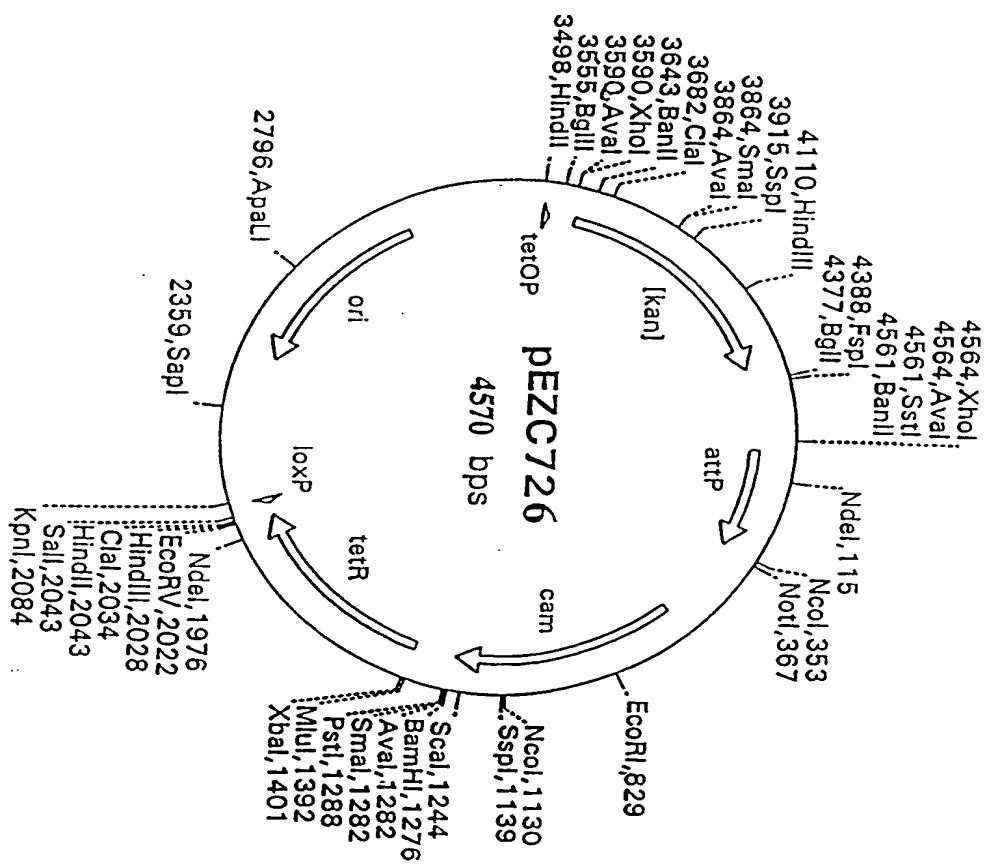
Figure 1



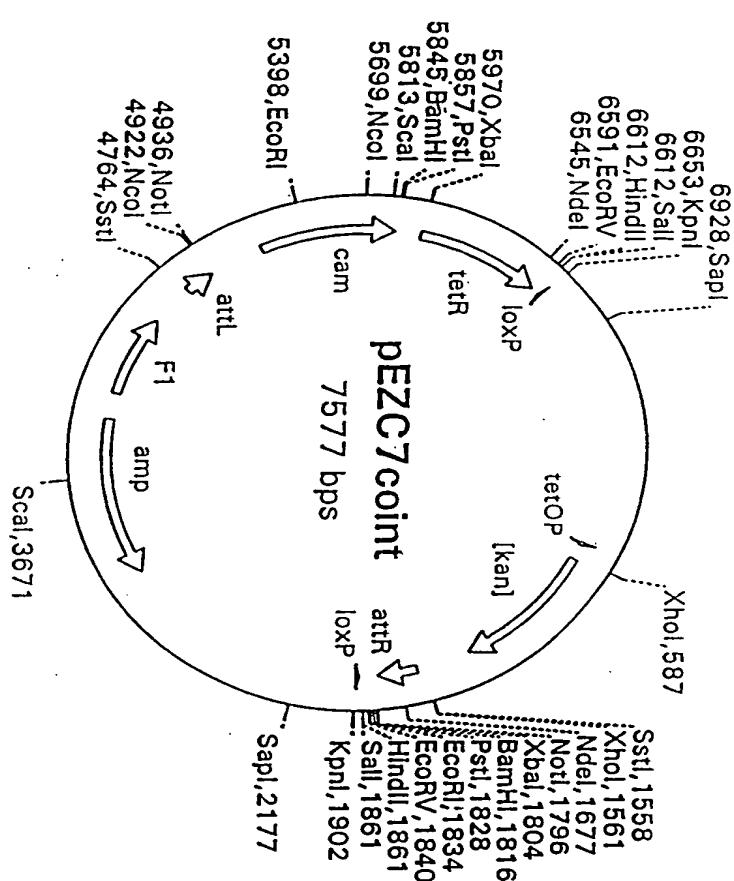
- FIGURE 2A -



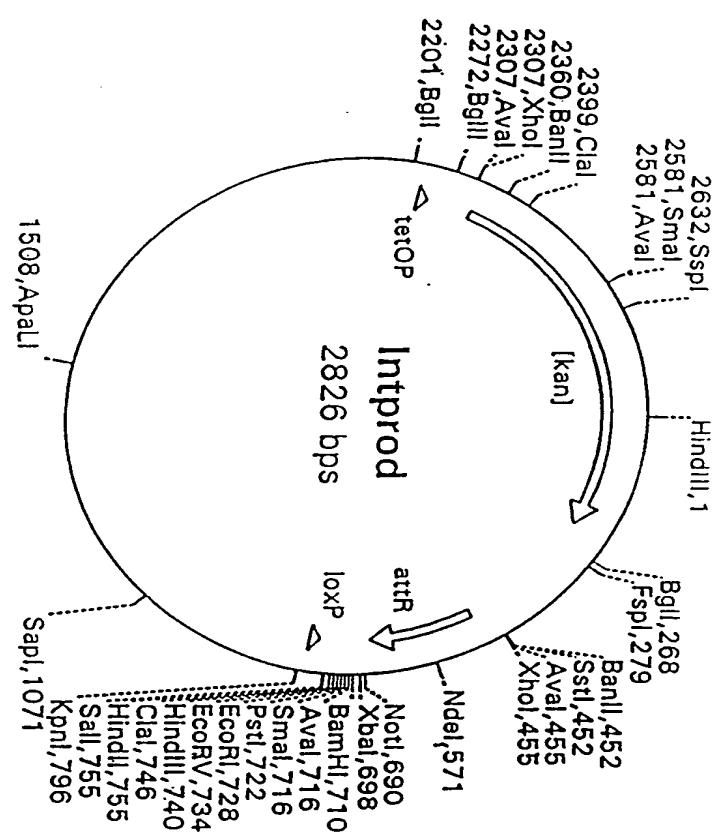
- FIGURE 2B -



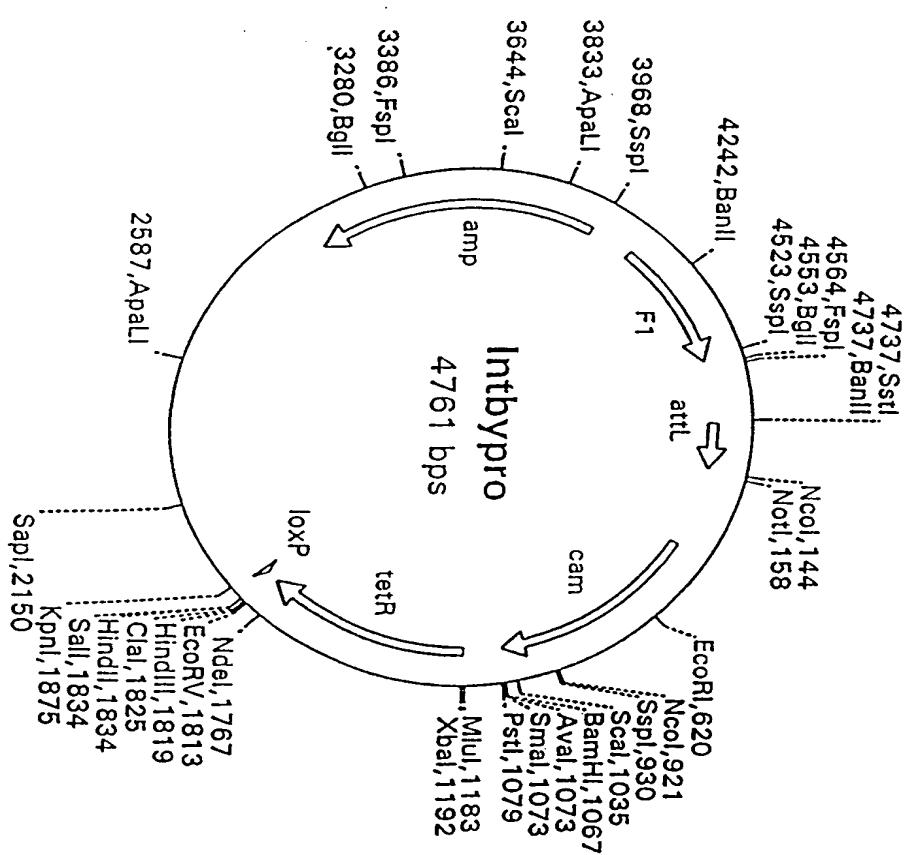
- FIGURE 2C -



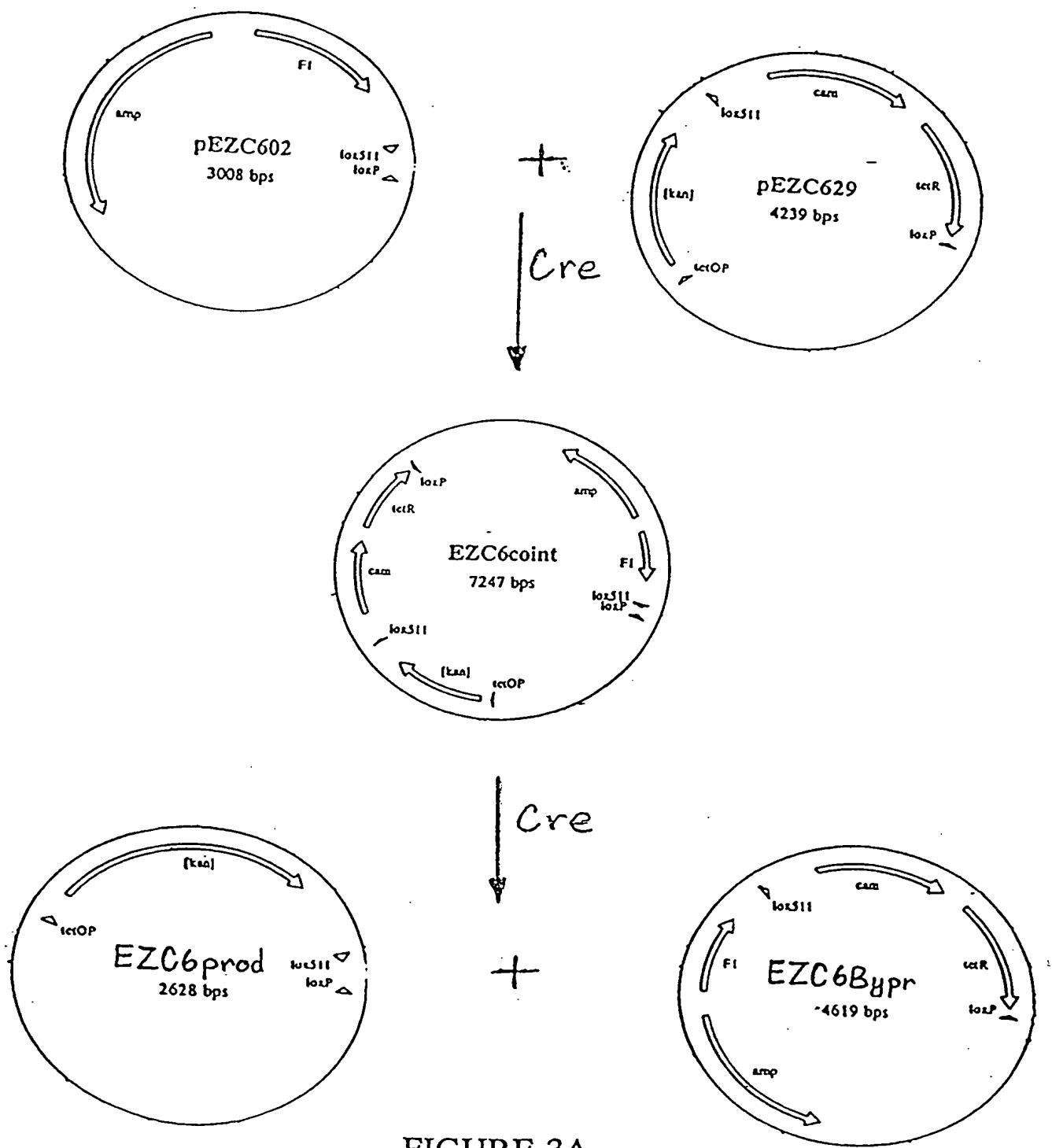
- FIGURE 2D -



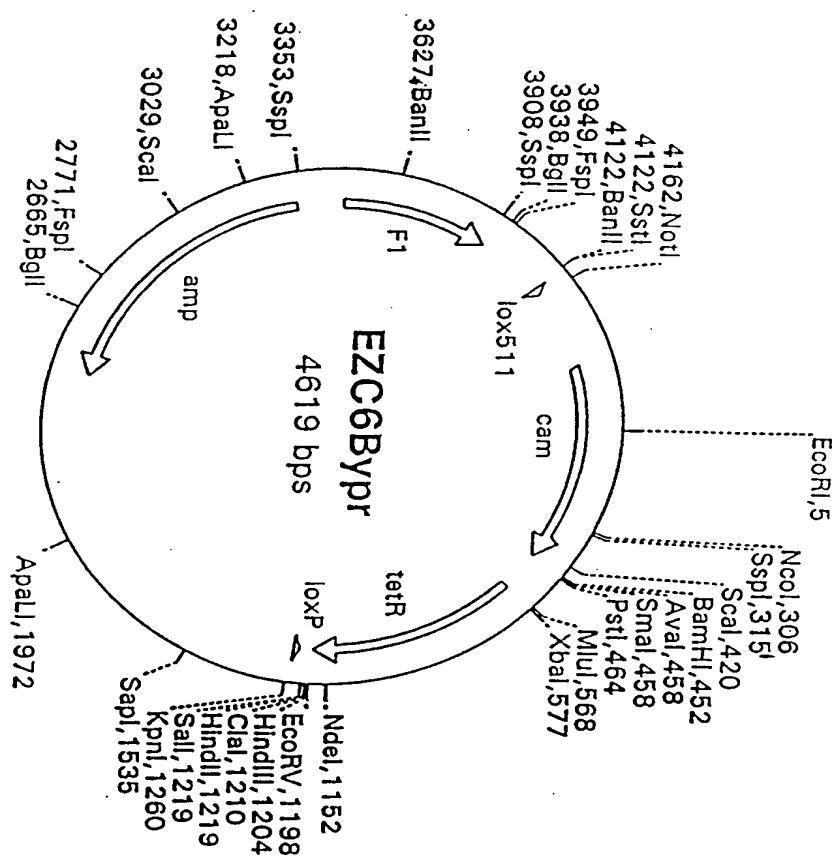
- FIGURE 2E -



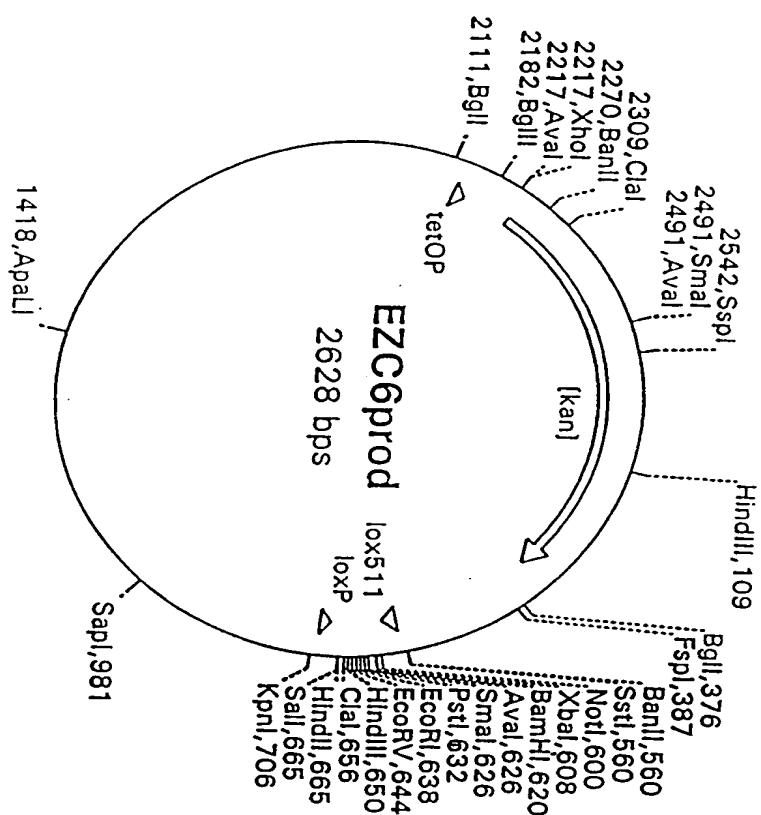
- FIGURE 2F -



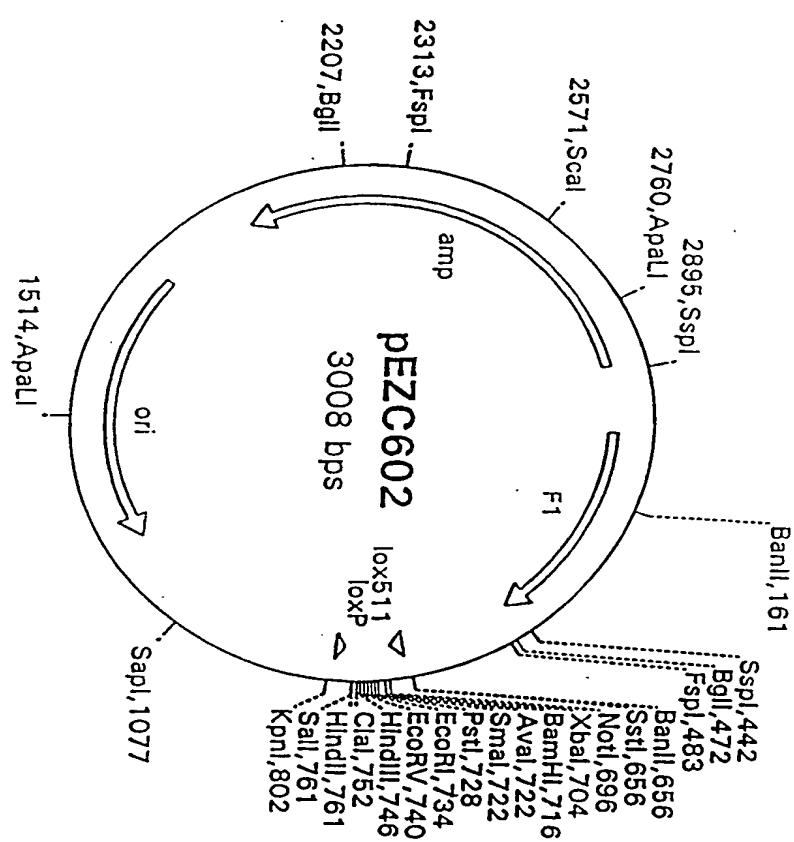
- FIGURE 3A -



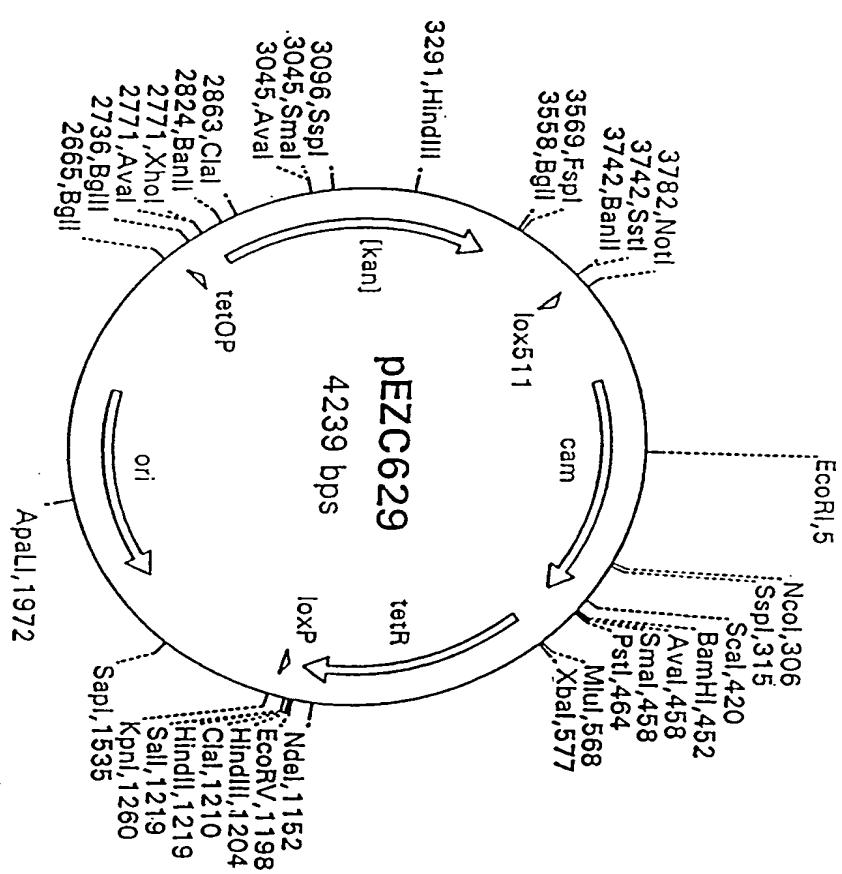
- FIGURE 3B -



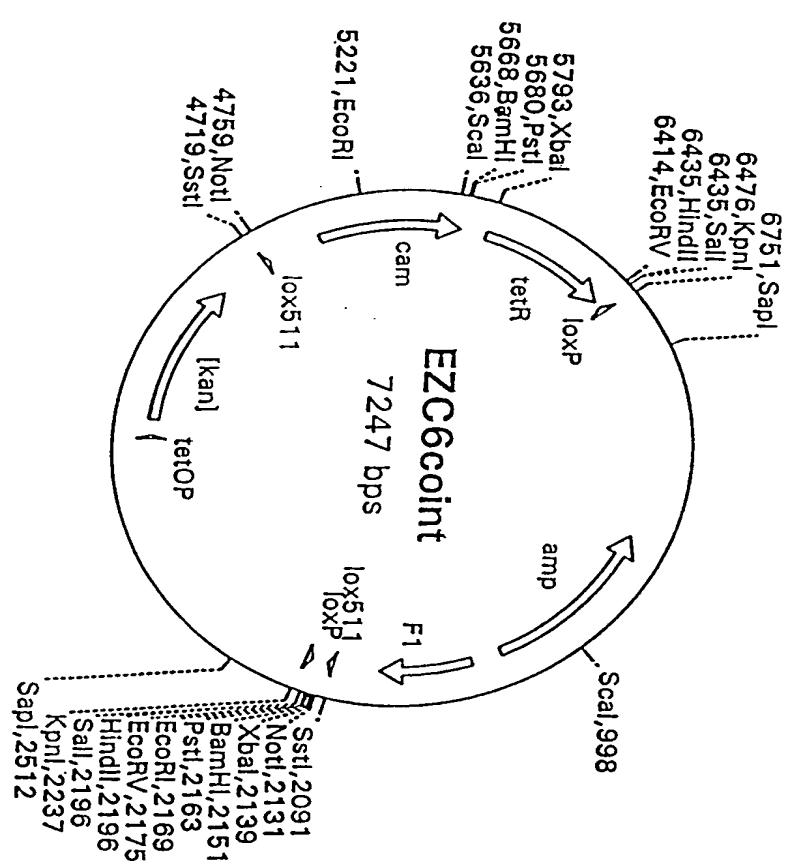
- FIGURE 3C -



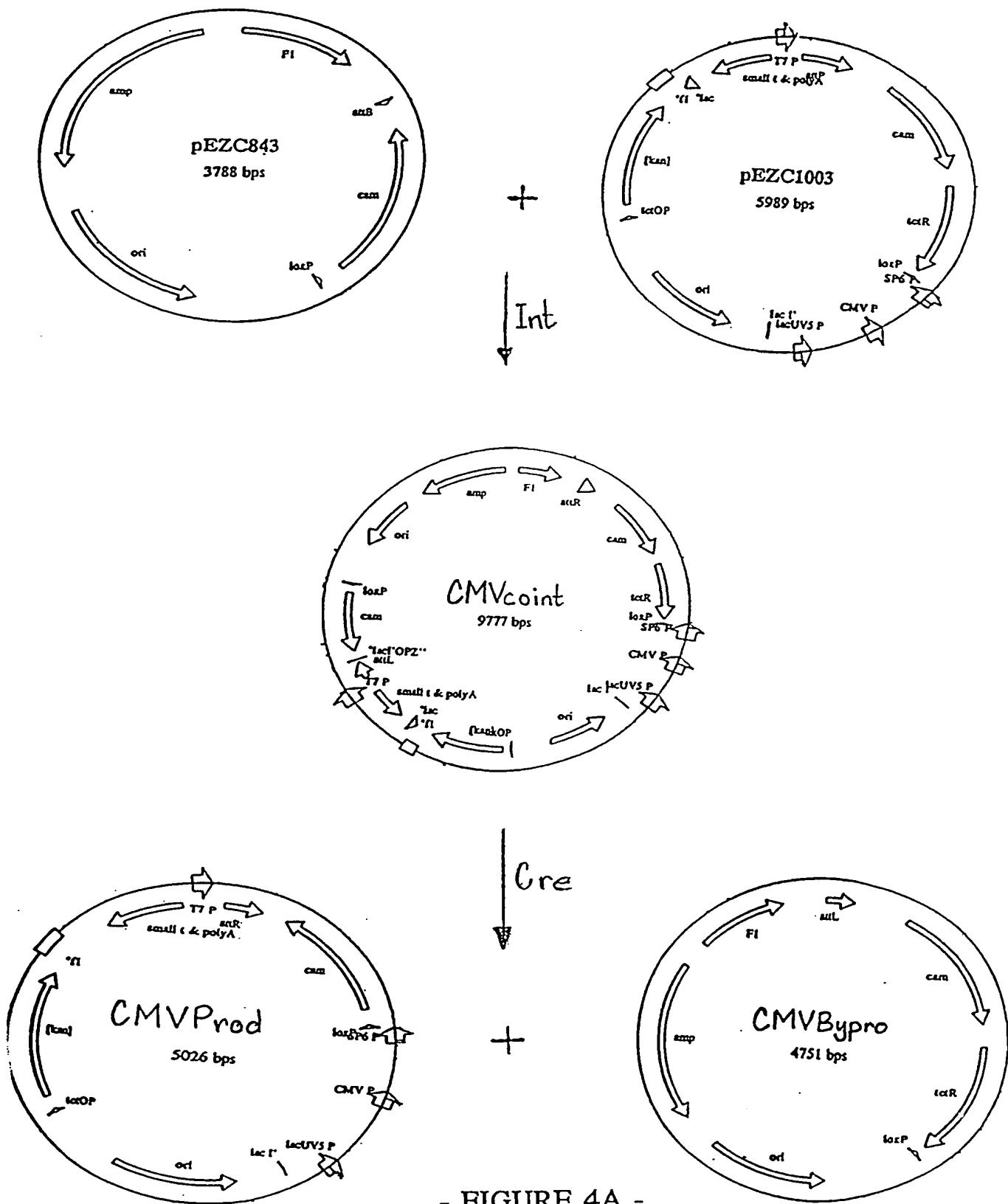
- FIGURE 3D -



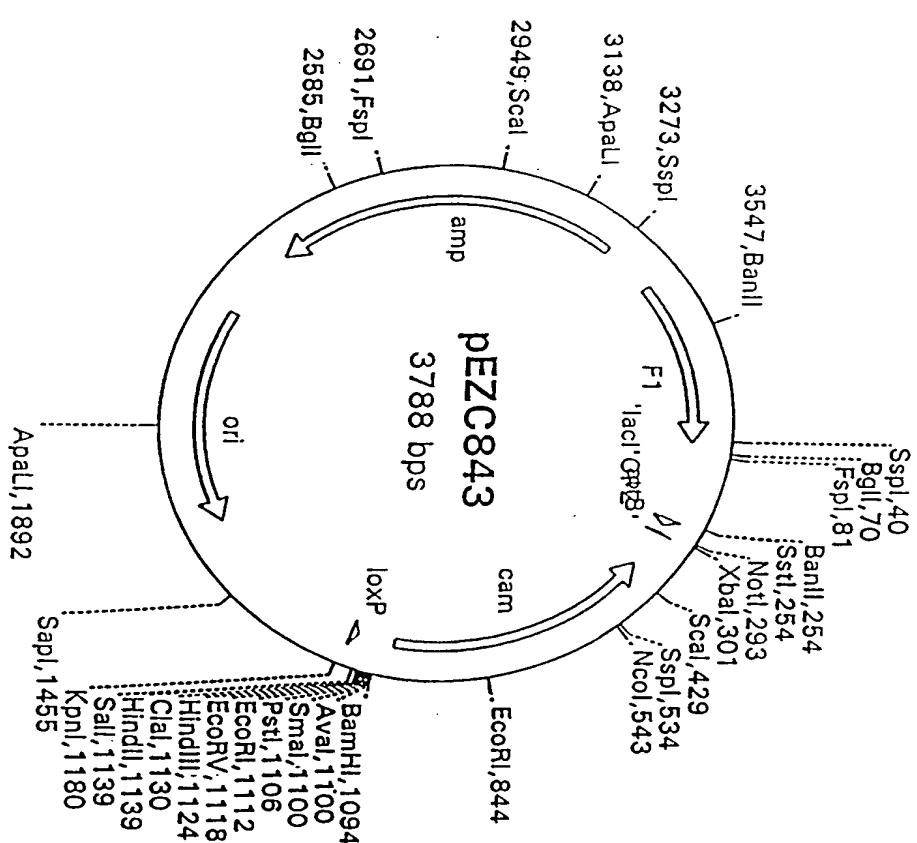
- FIGURE 3E -



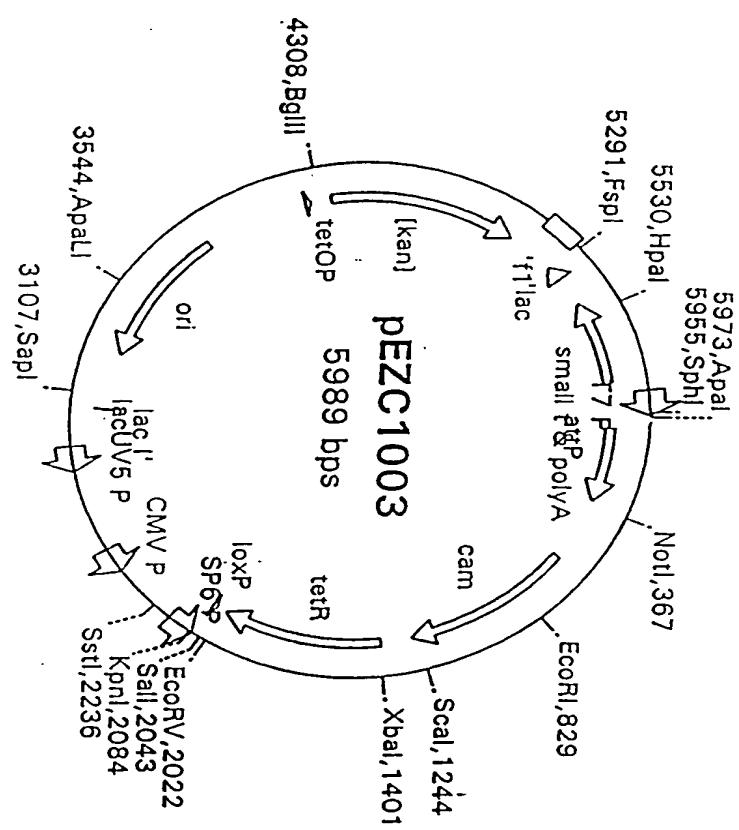
- FIGURE 3F -



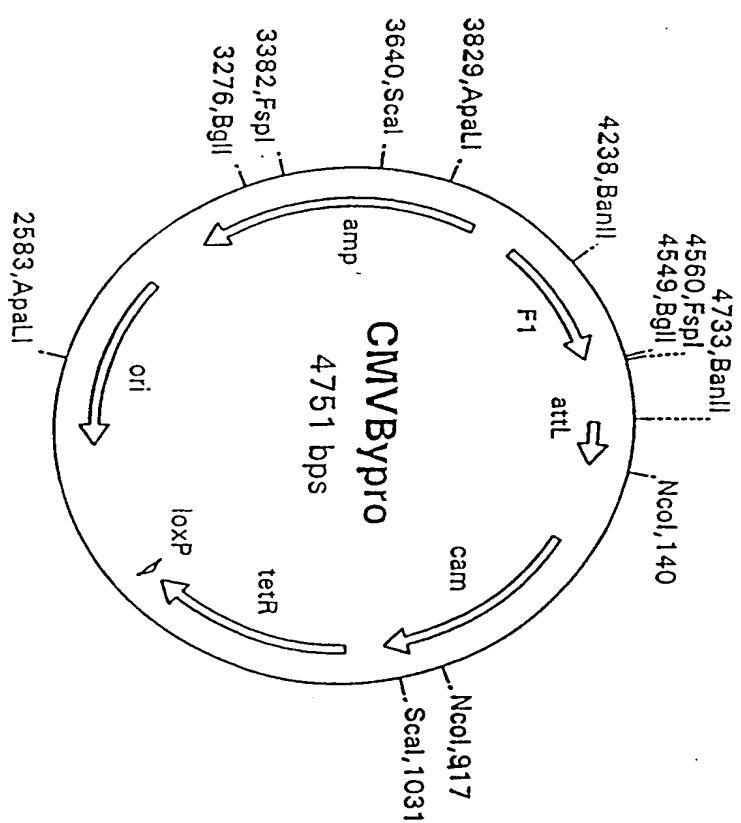
- FIGURE 4A -



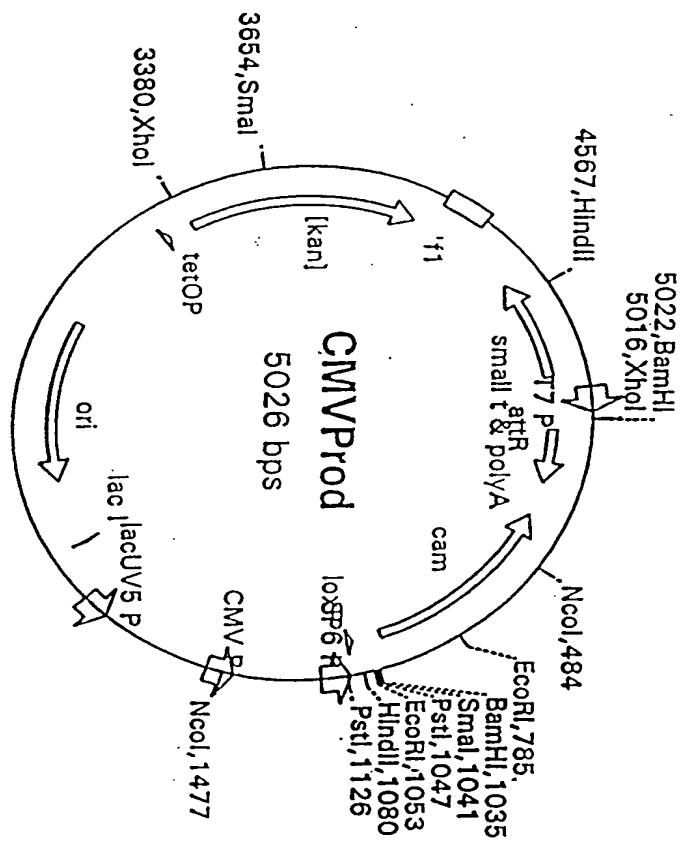
- FIGURE 4B -



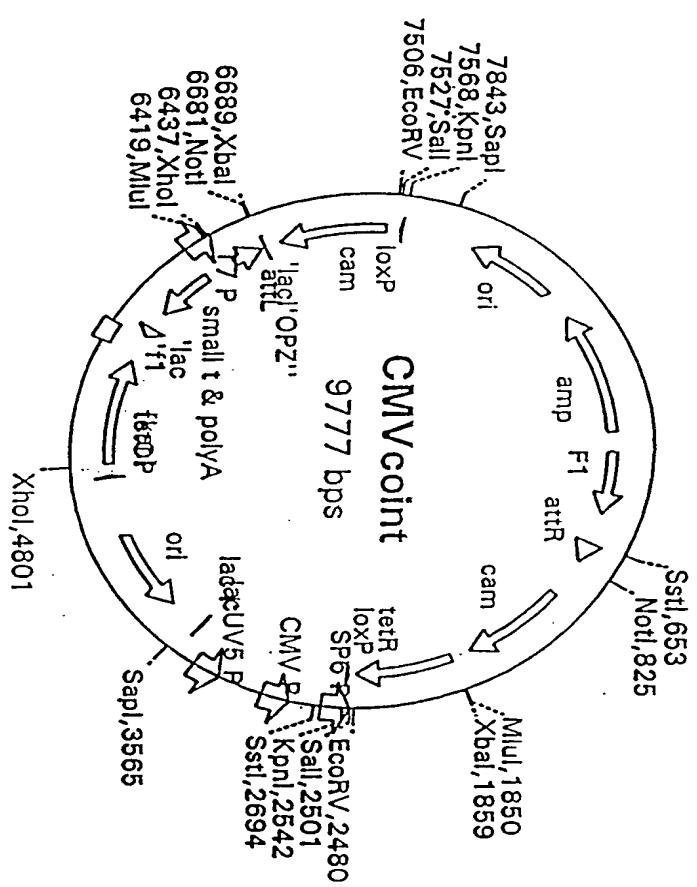
- FIGURE 4C -



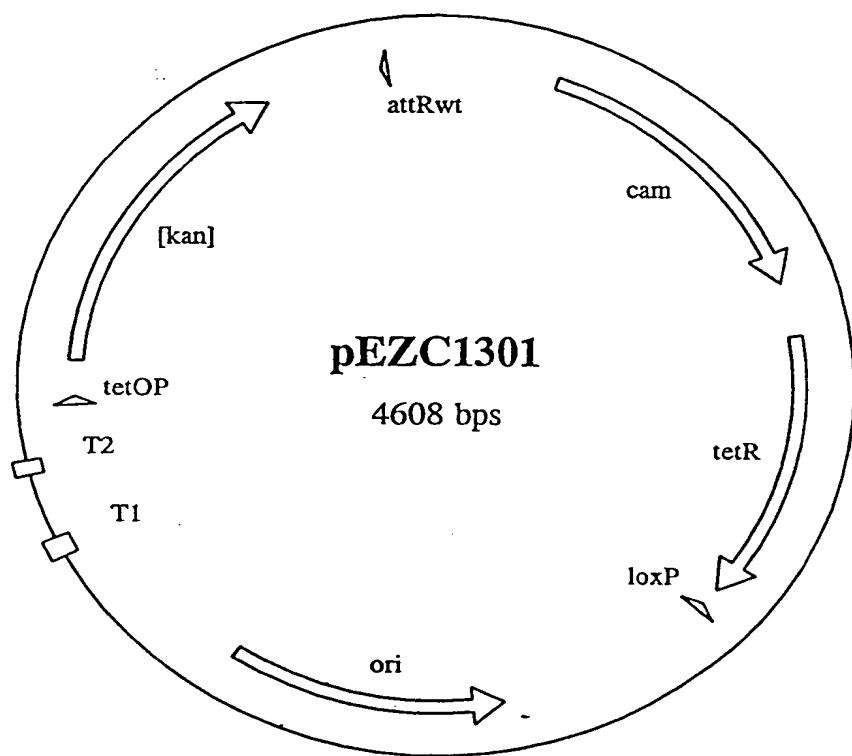
- FIGURE 4D -



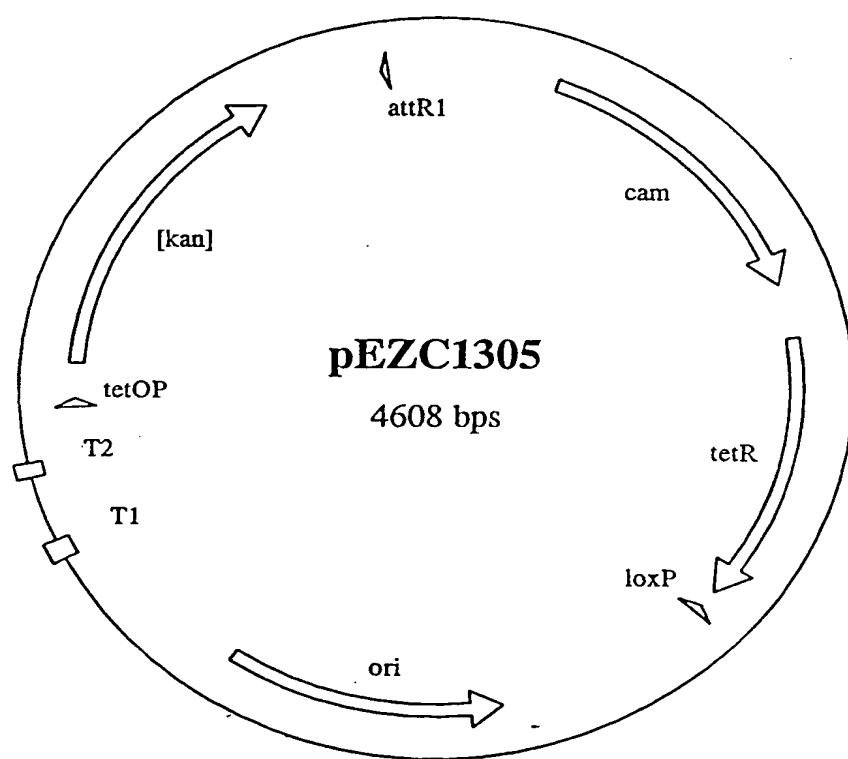
- FIGURE 4E -



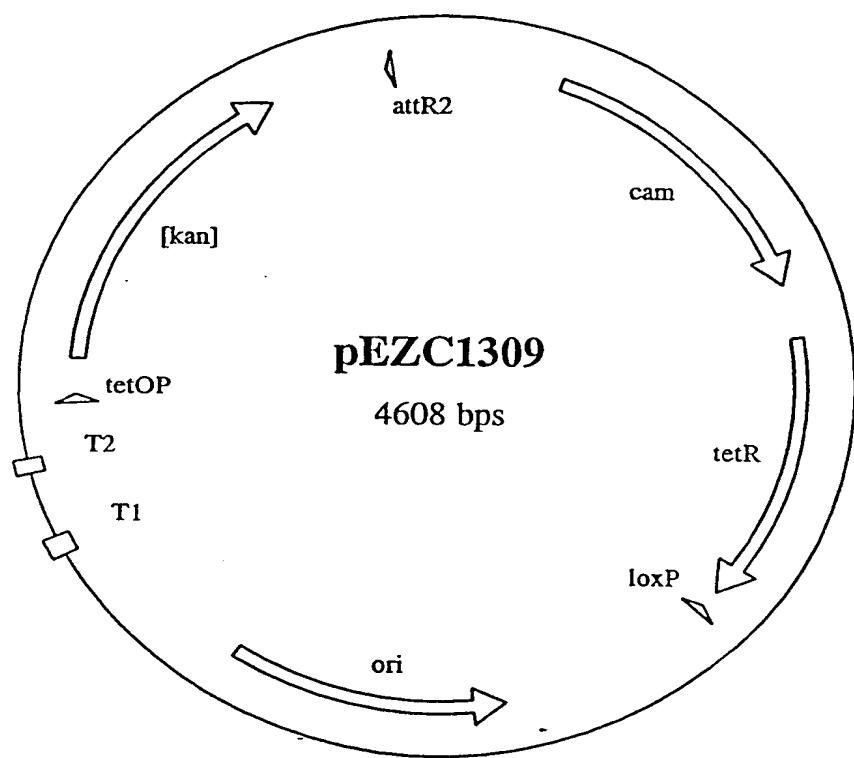
- FIGURE 4F -



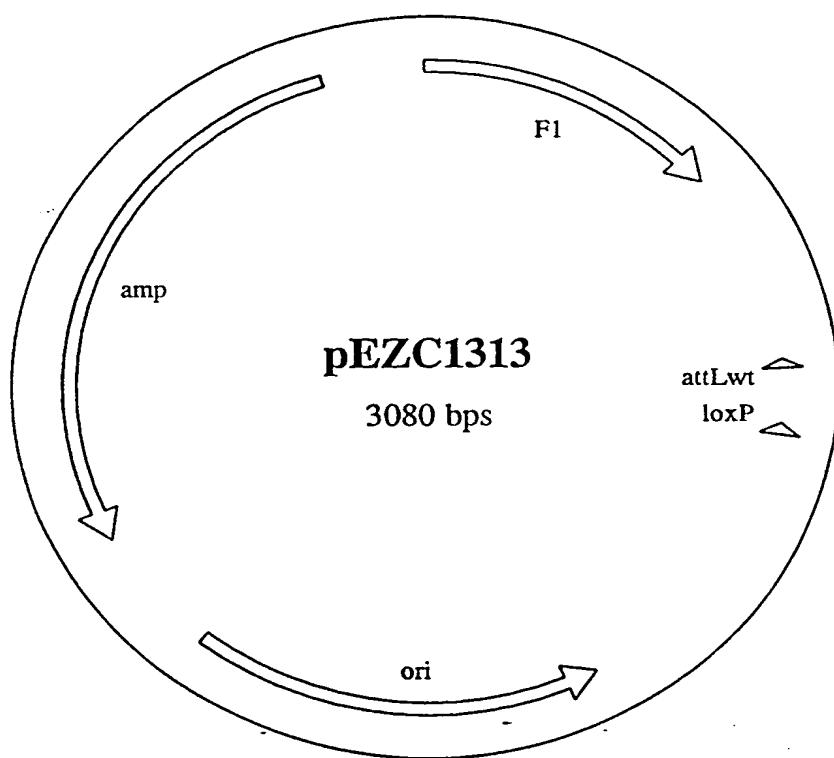
- FIGURE 5A -



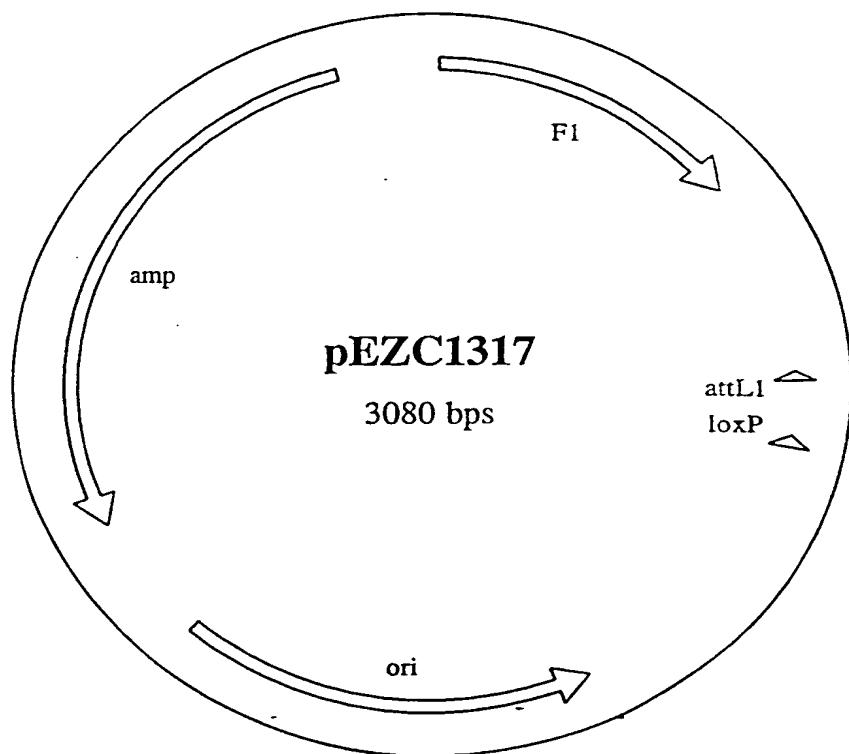
- FIGURE 5B -



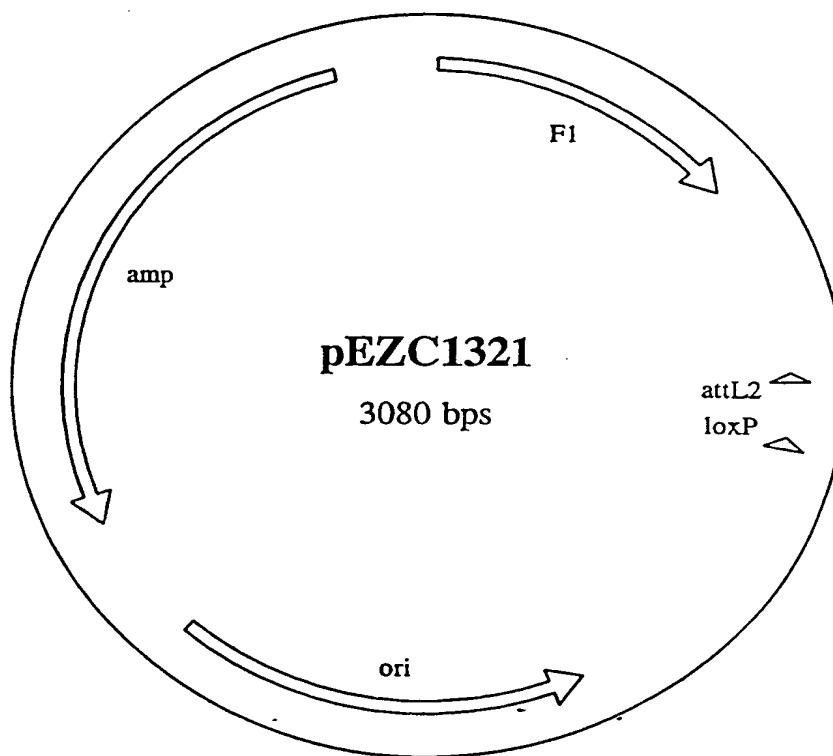
- FIGURE 5C -



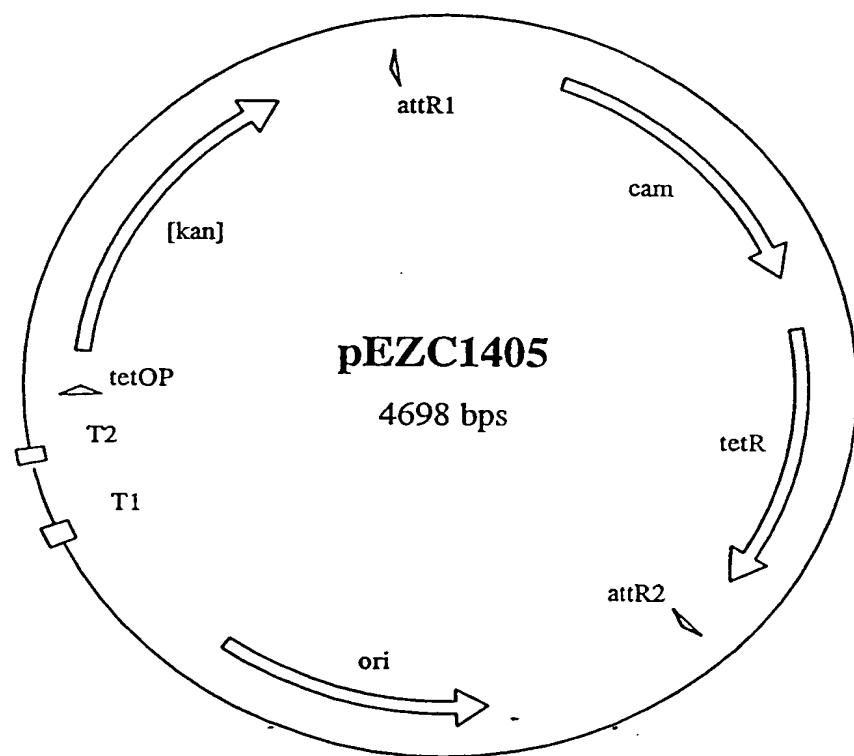
- FIGURE 5D -



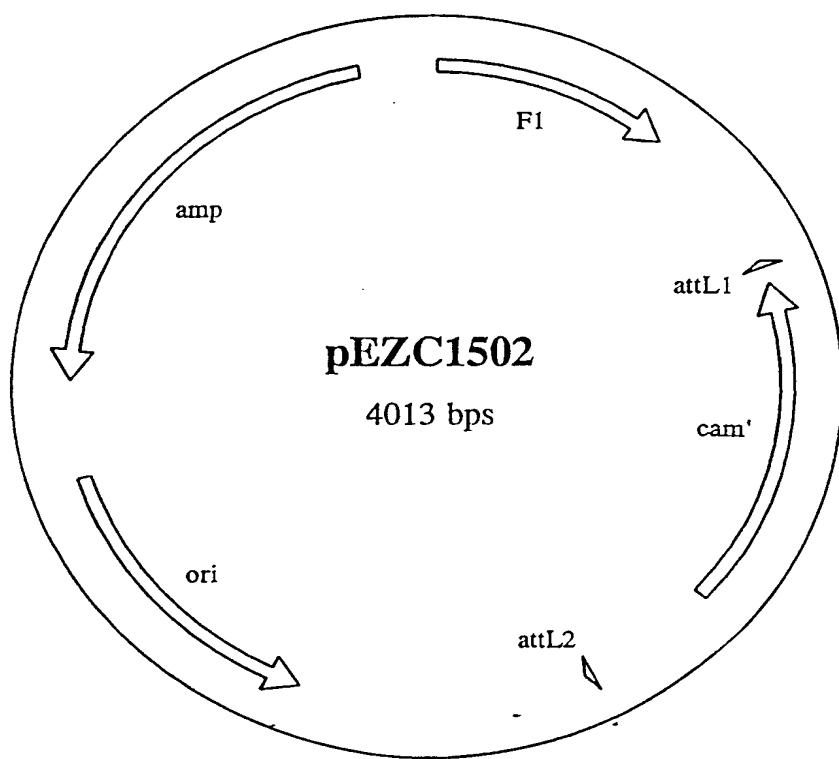
- FIGURE 5E -



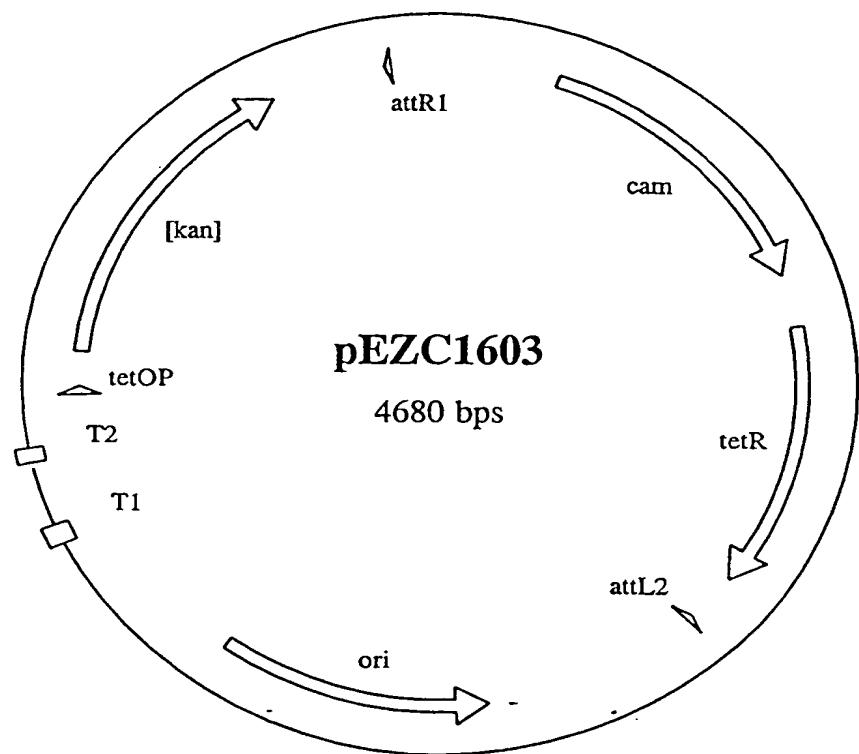
- FIGURE 5F -



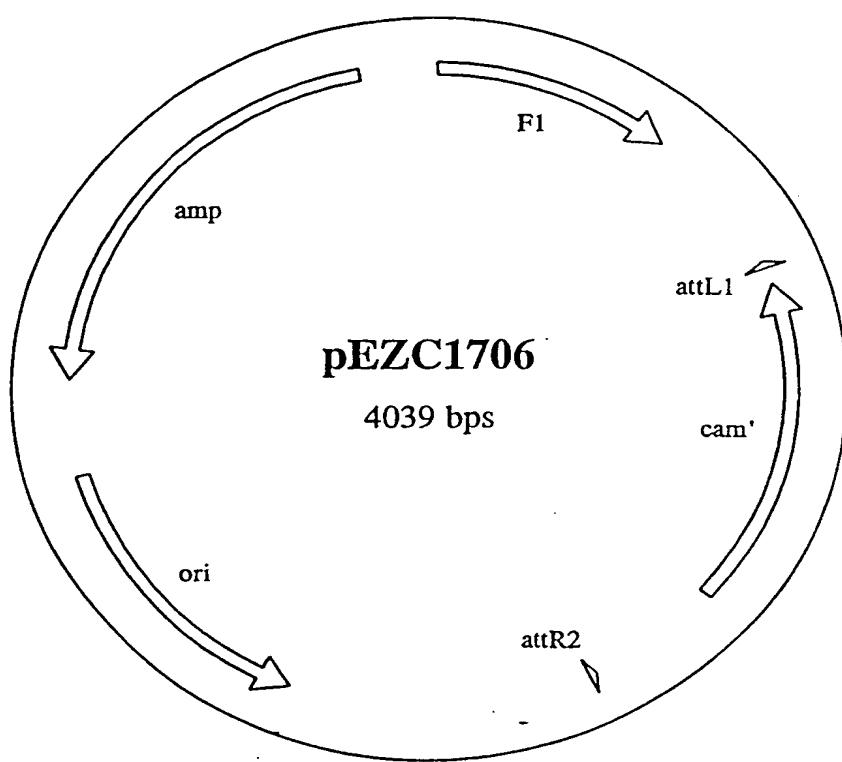
- FIGURE 5G -



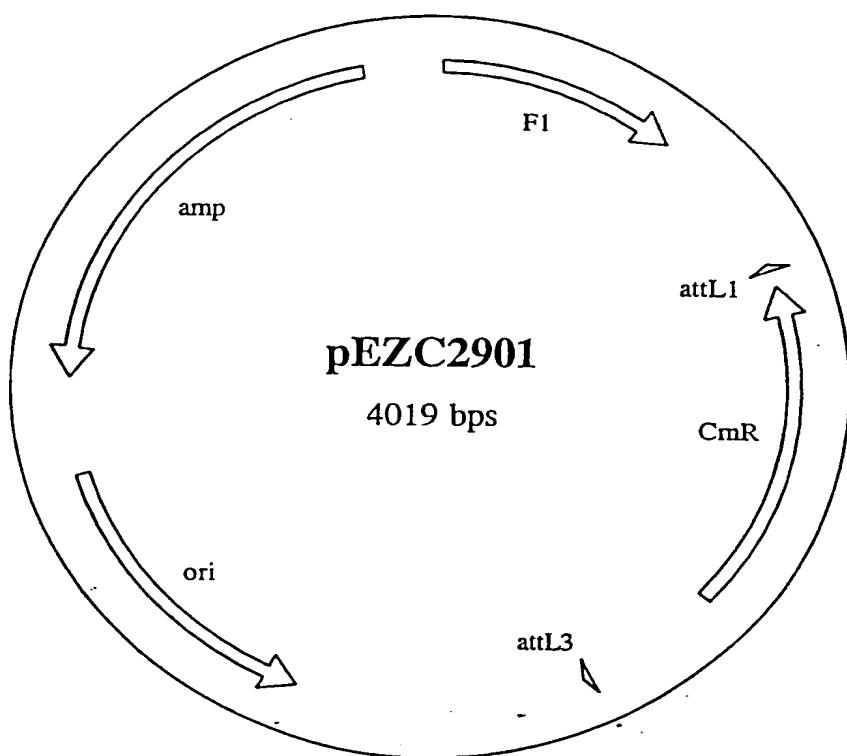
- FIGURE 5H -



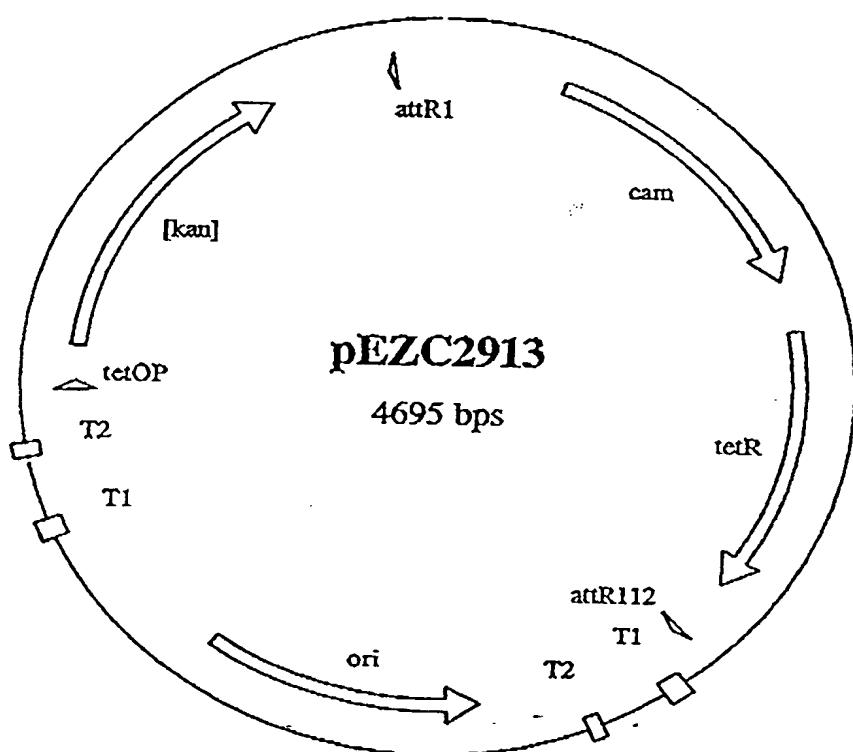
- FIGURE 6A -



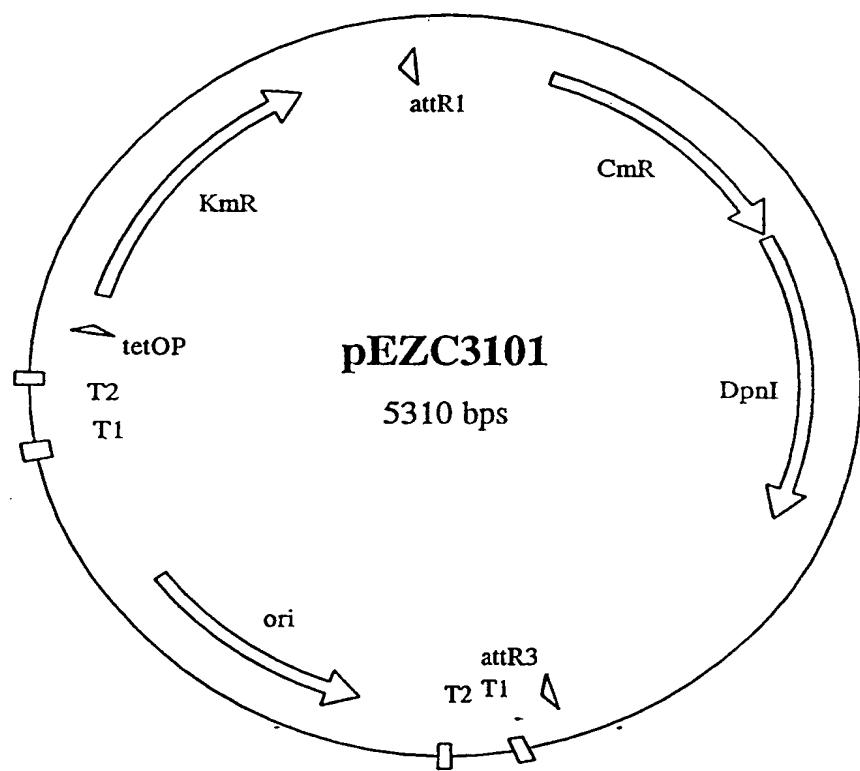
- FIGURE 6B -



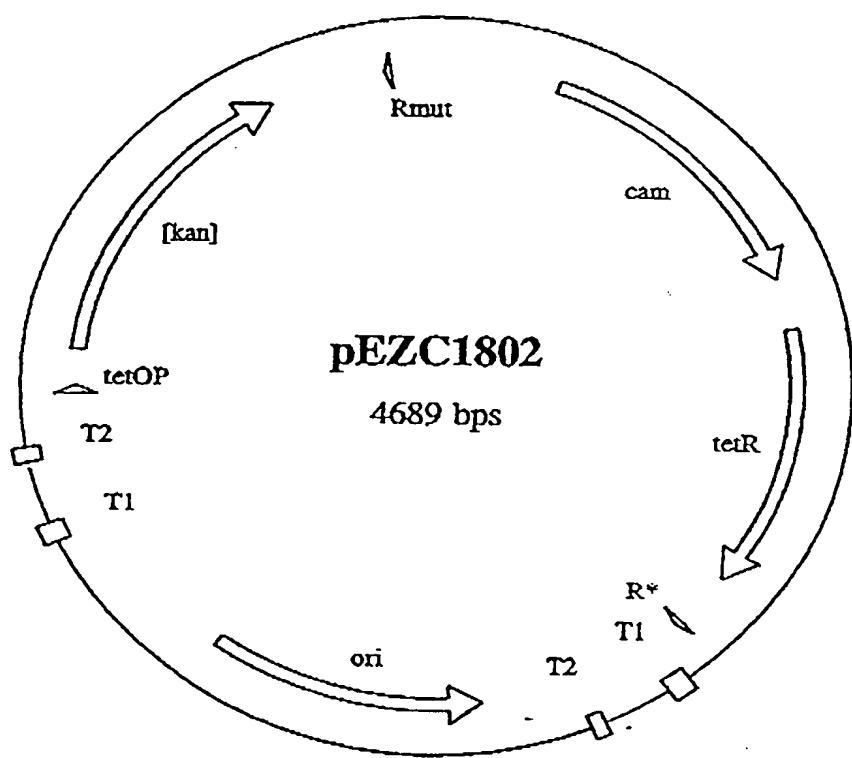
- FIGURE 7A -



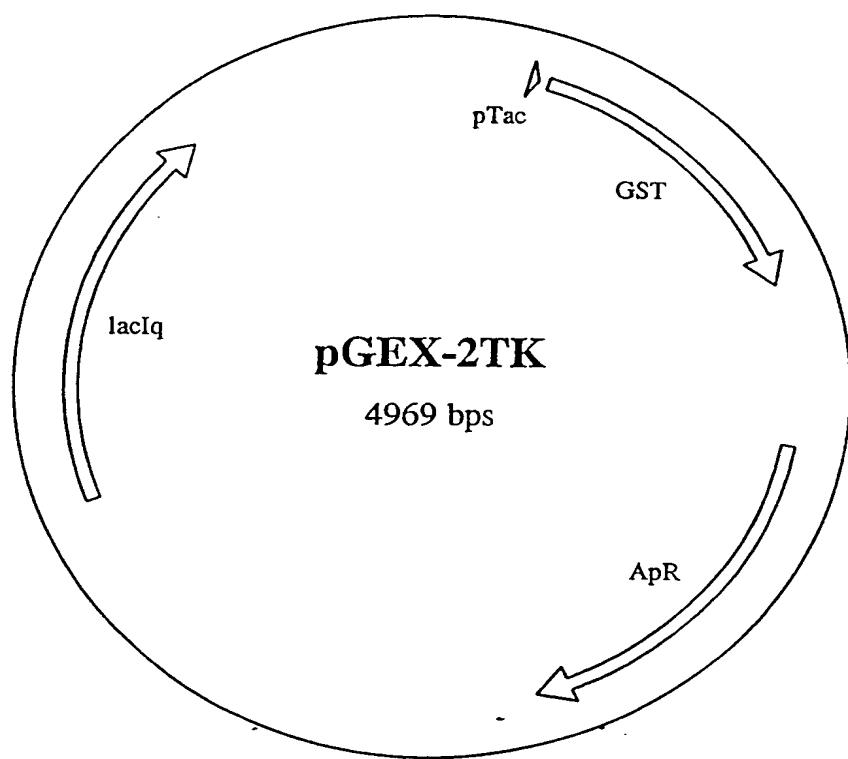
- FIGURE 7B -



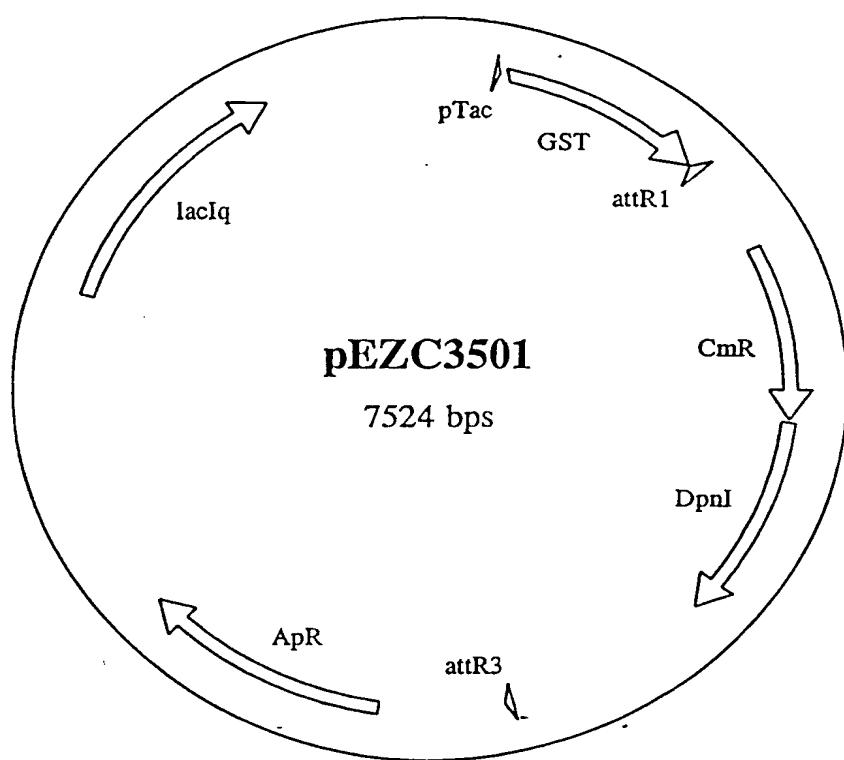
- FIGURE 7C -



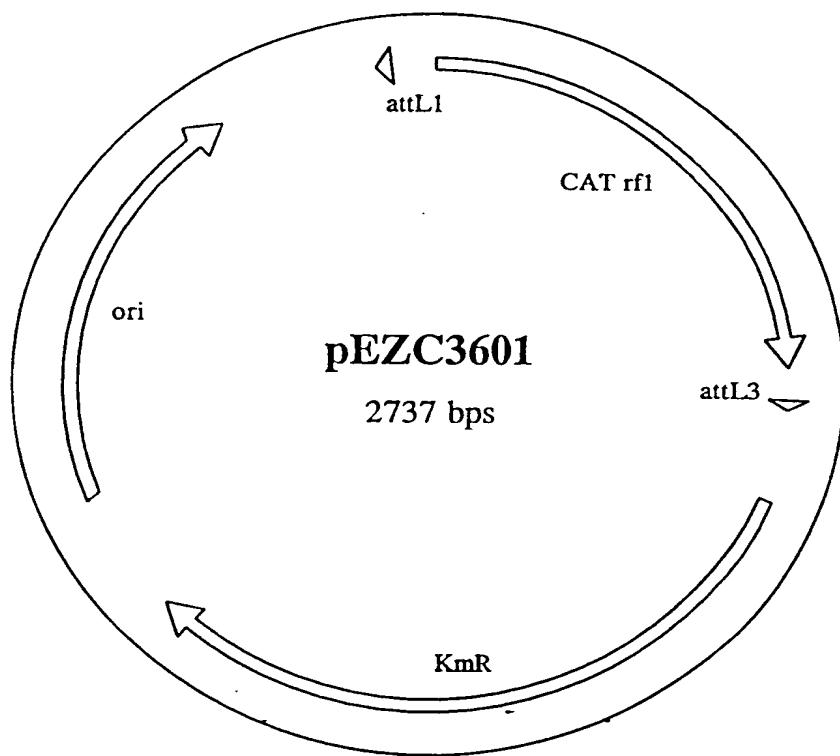
- FIGURE 7D -



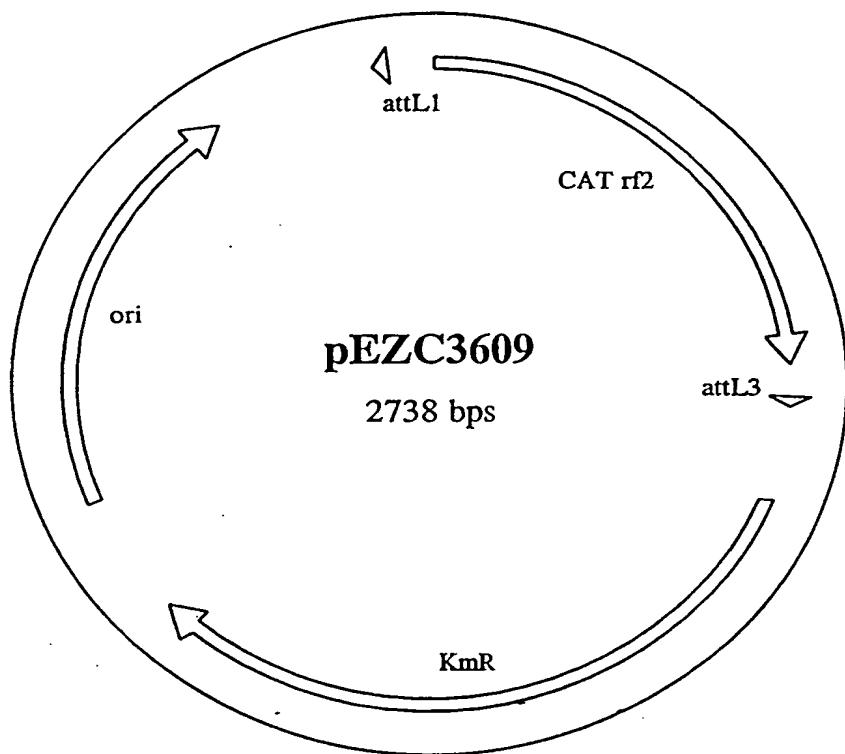
- FIGURE 8A -



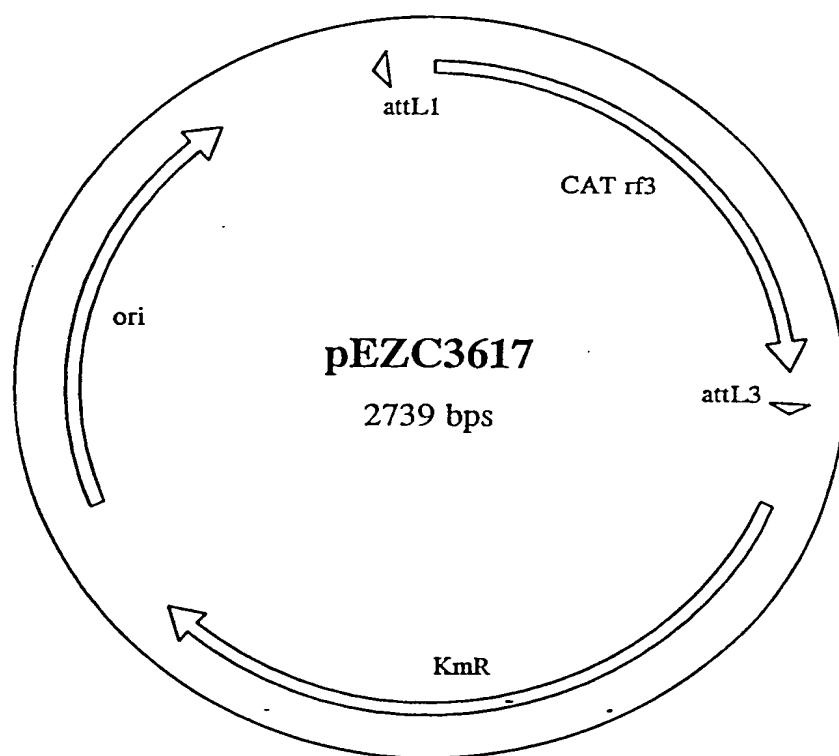
- FIGURE 8B -



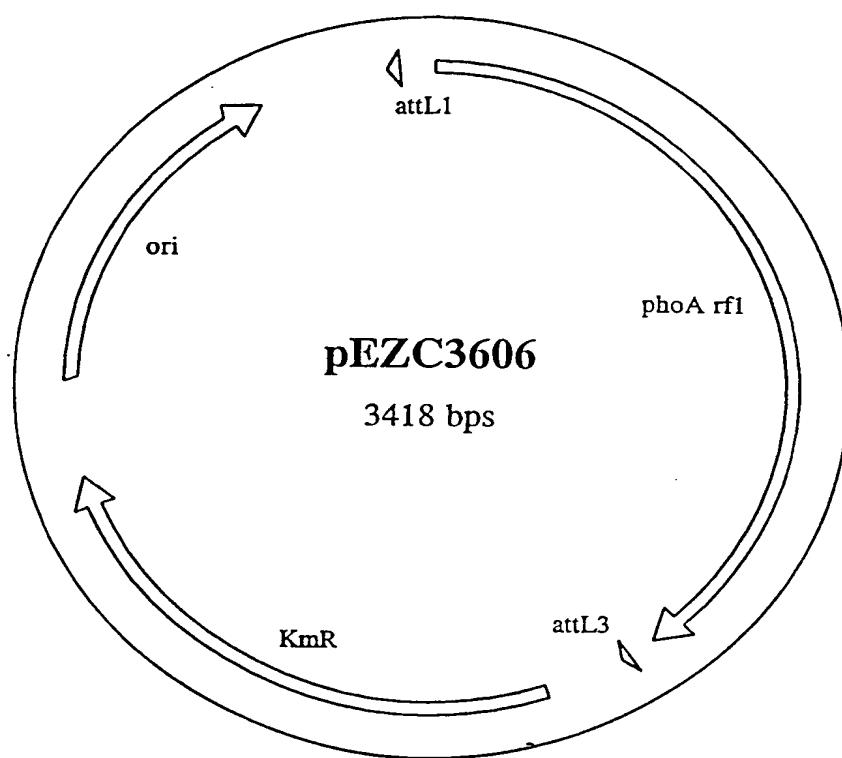
- FIGURE 8C -



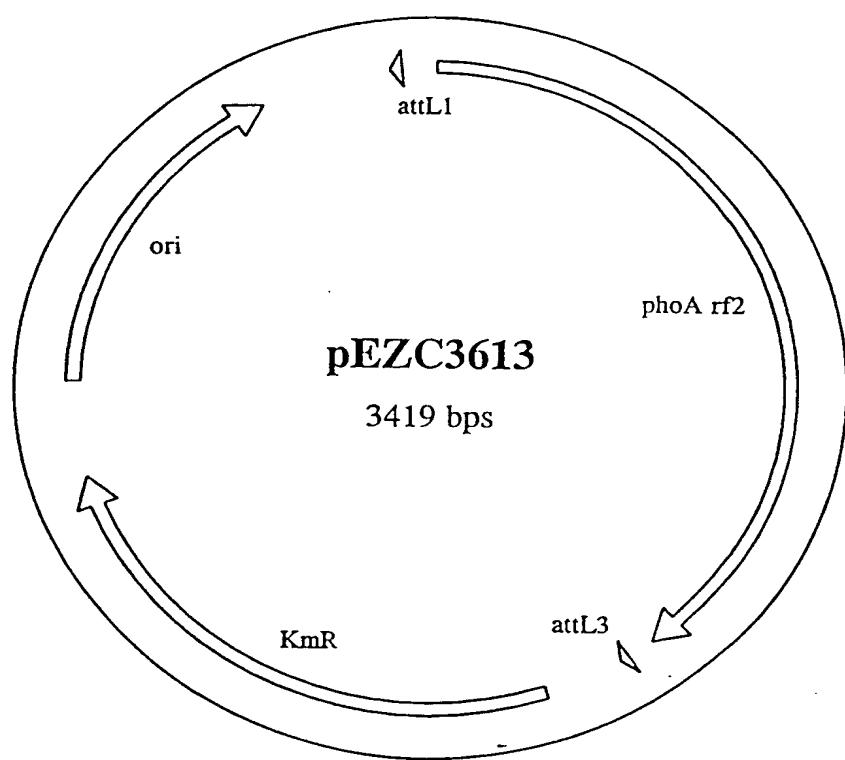
- FIGURE 8D -



- FIGURE 8E -



- FIGURE 8F -



- FIGURE 8G -

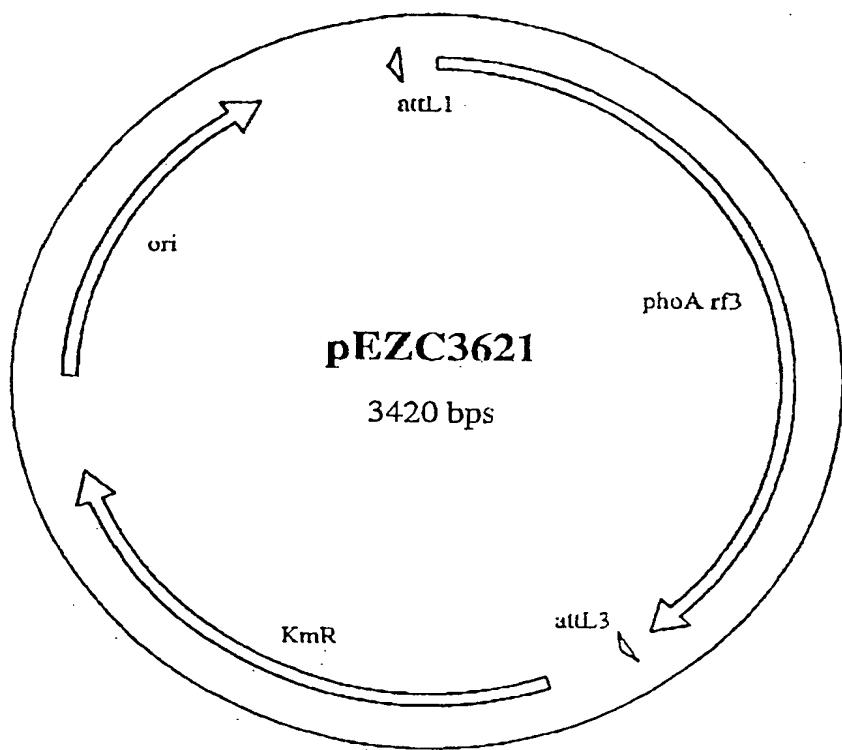


Figure 8H

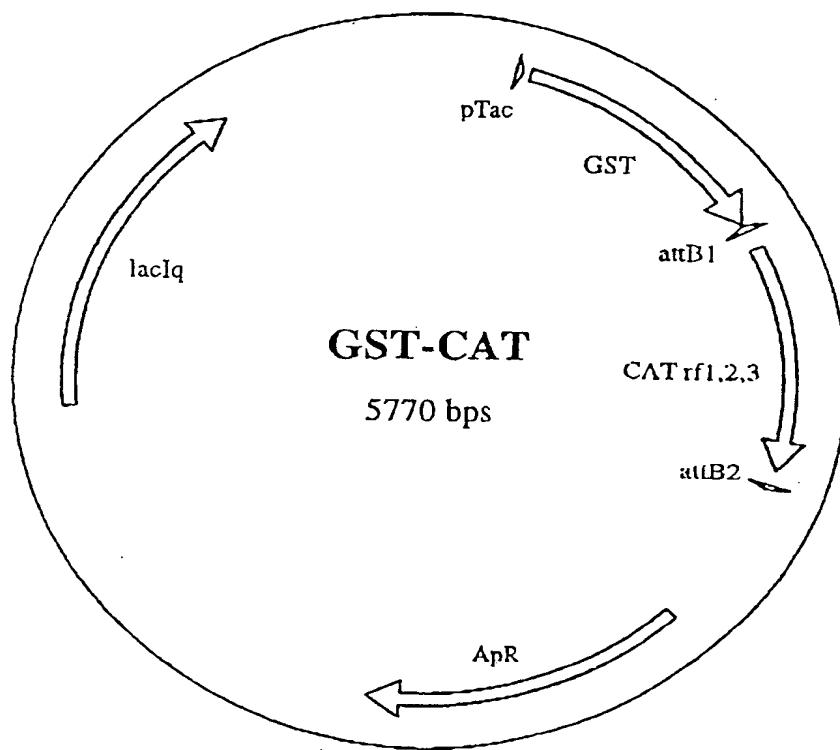


Figure 8I

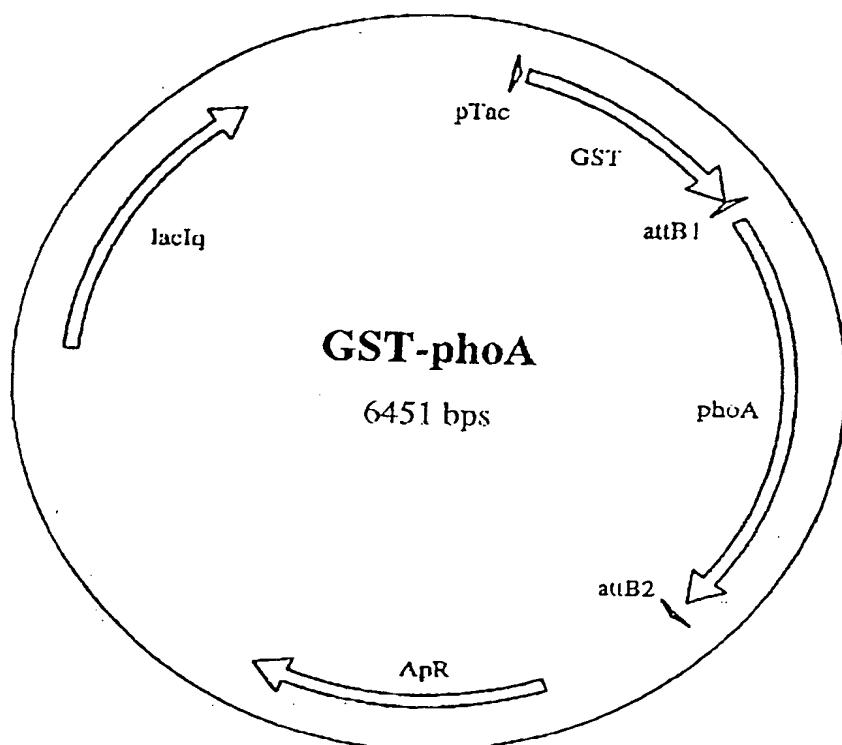


Figure 8J

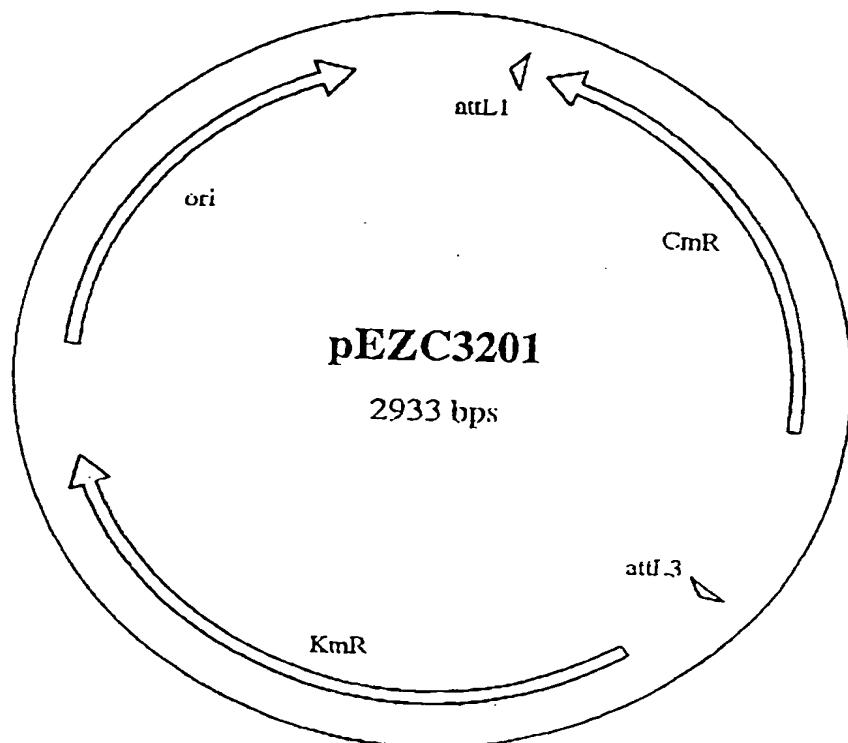
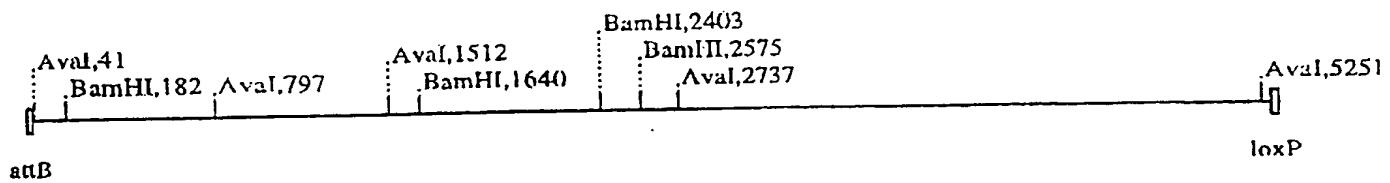


FIGURE 8K



5.2kbPCRprod (5327 bps)

FIGURE 9A

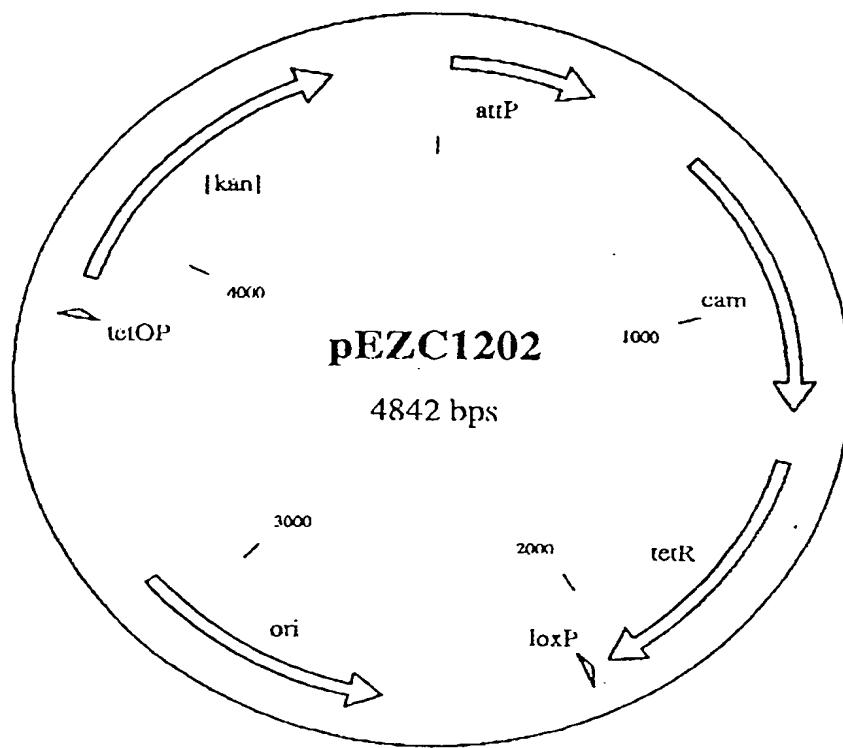


FIGURE 9B

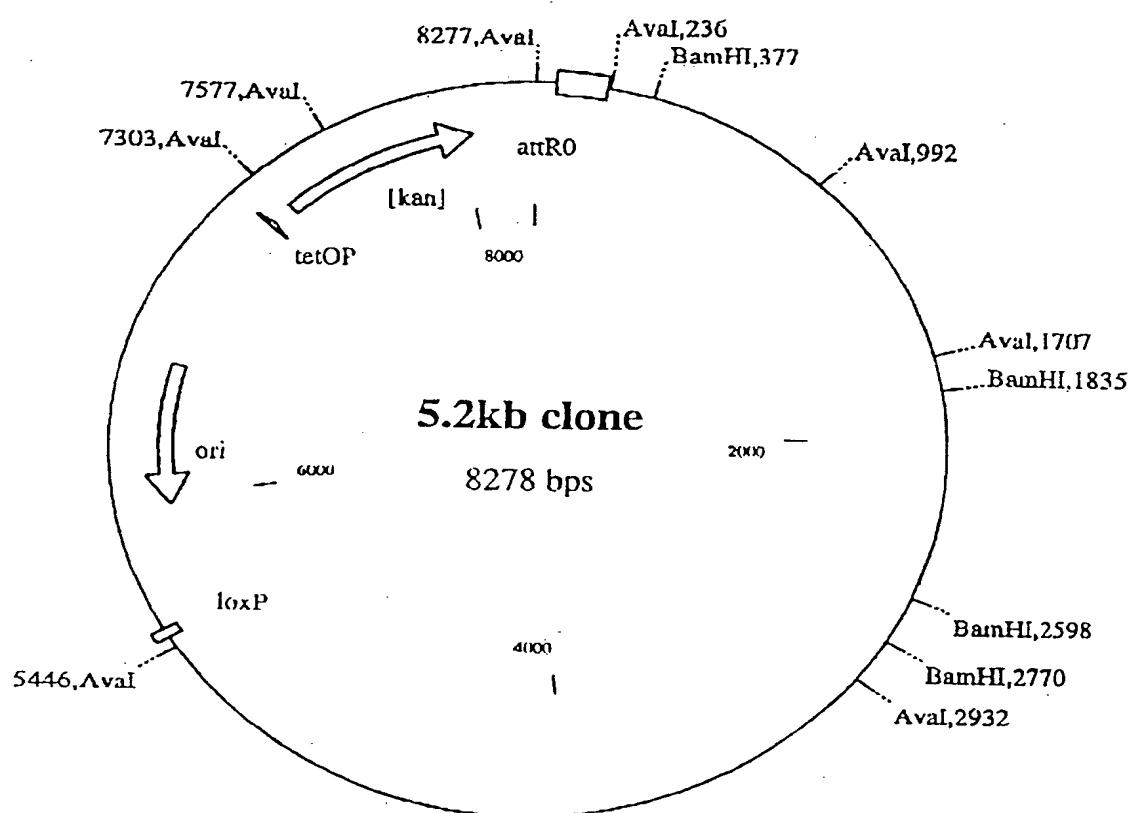


FIGURE 9C

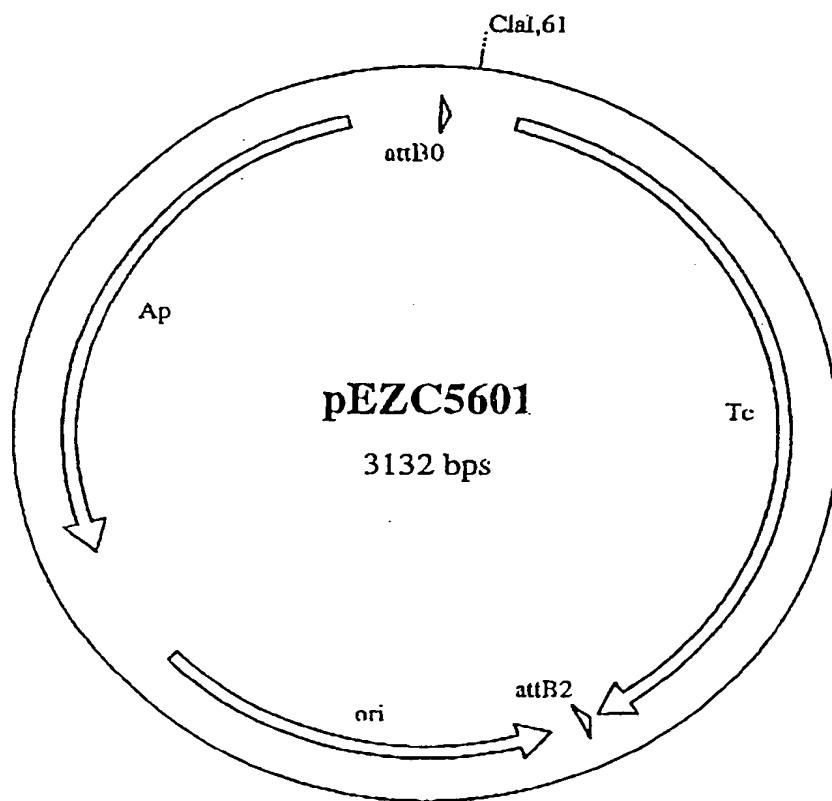


Figure 10A

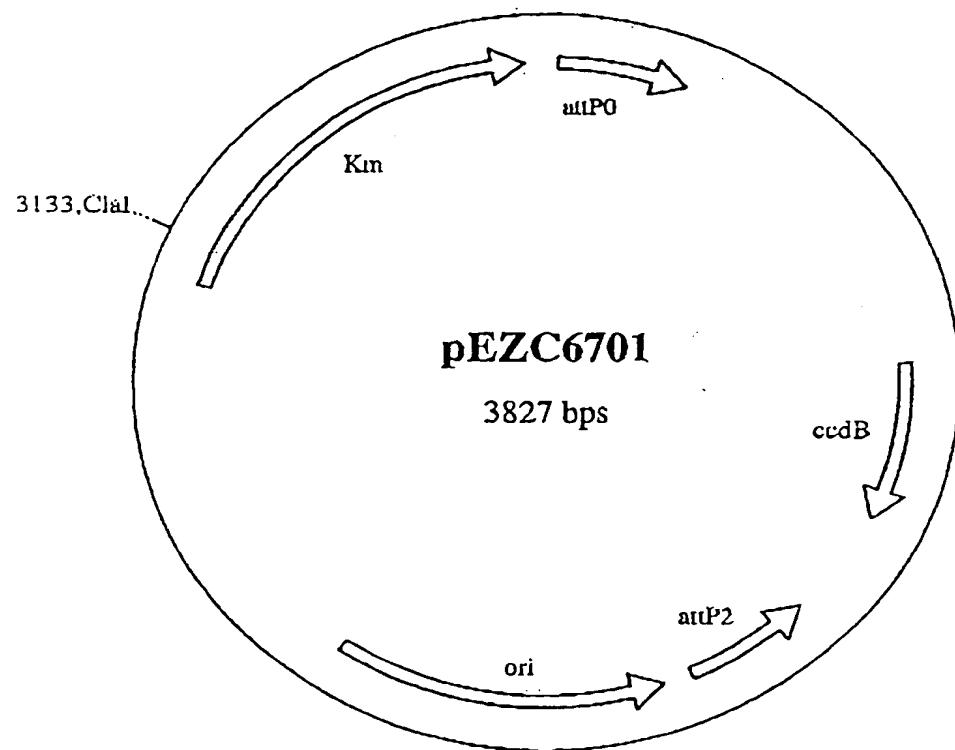


Figure 10B

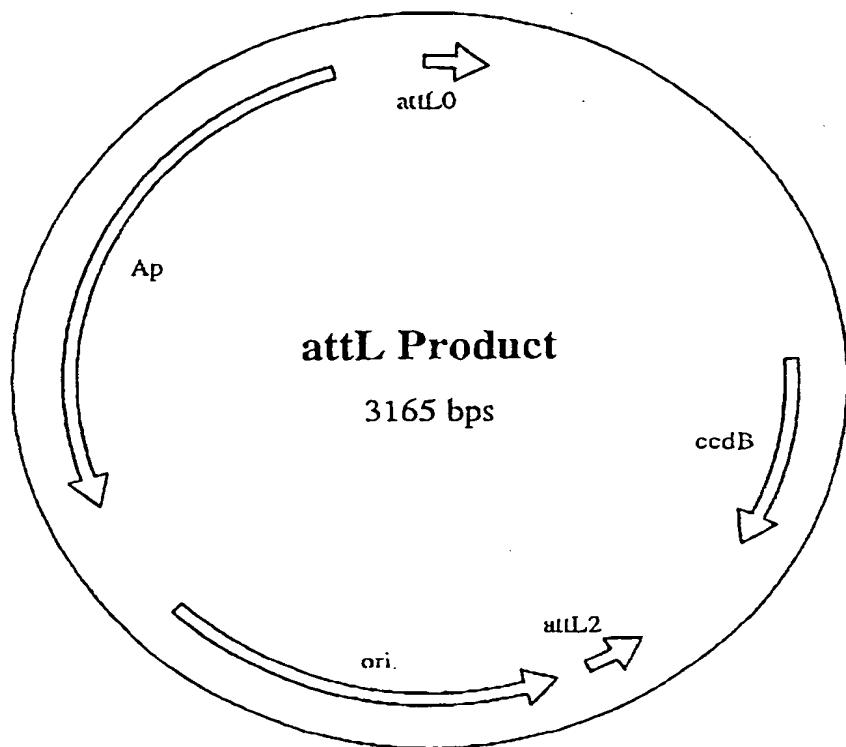


Figure 10C

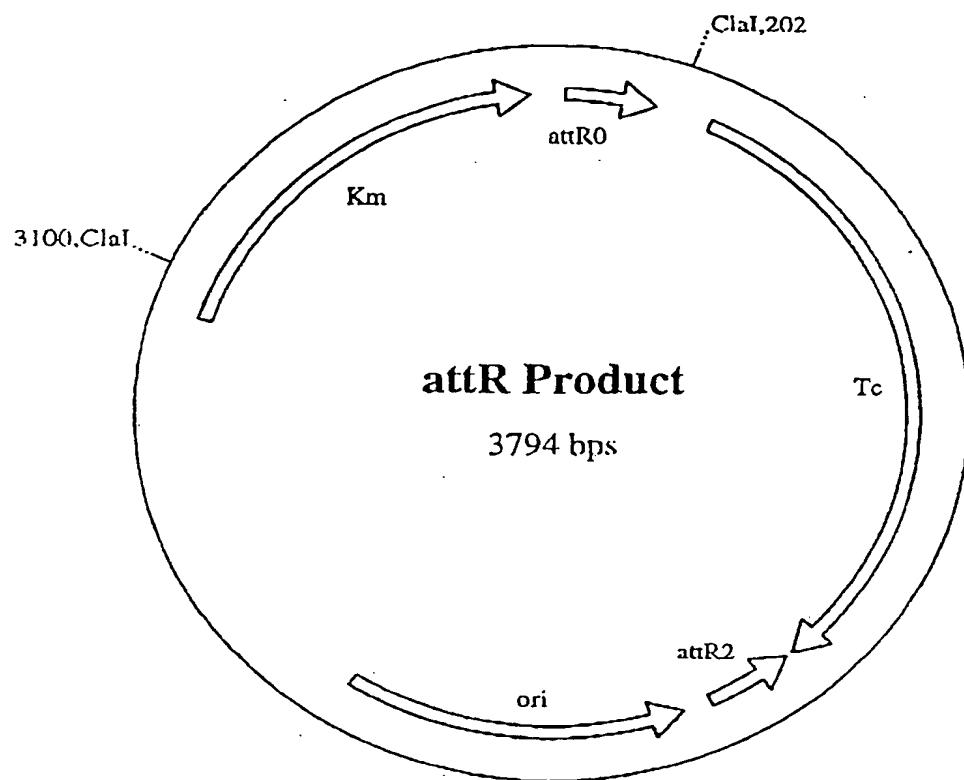


Figure 10D

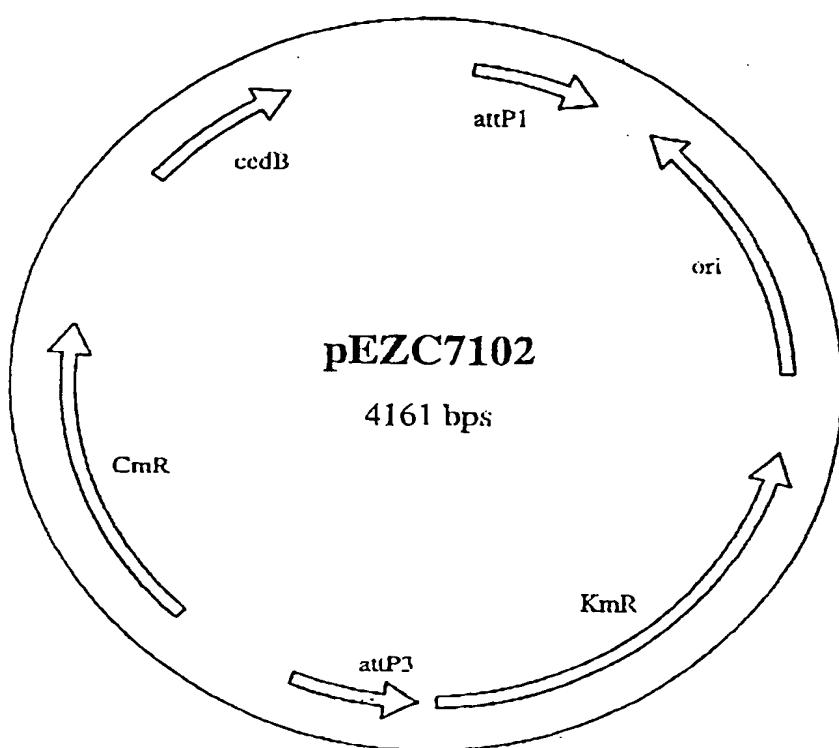


Figure 11A

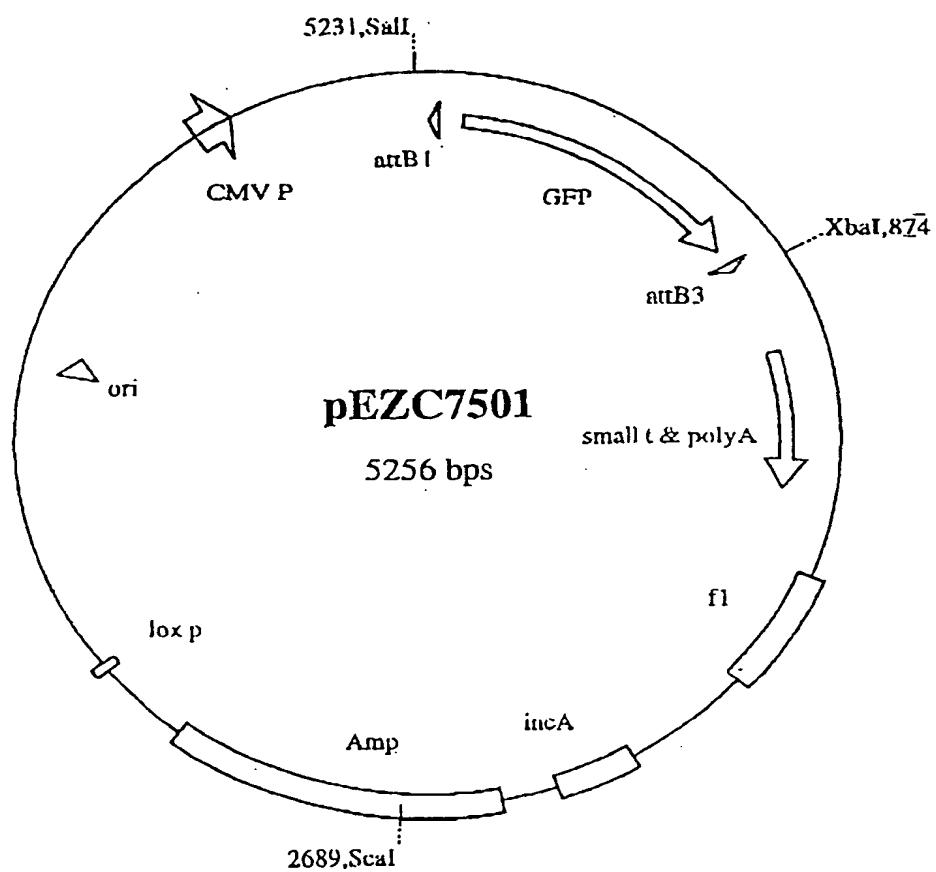


figure 11B

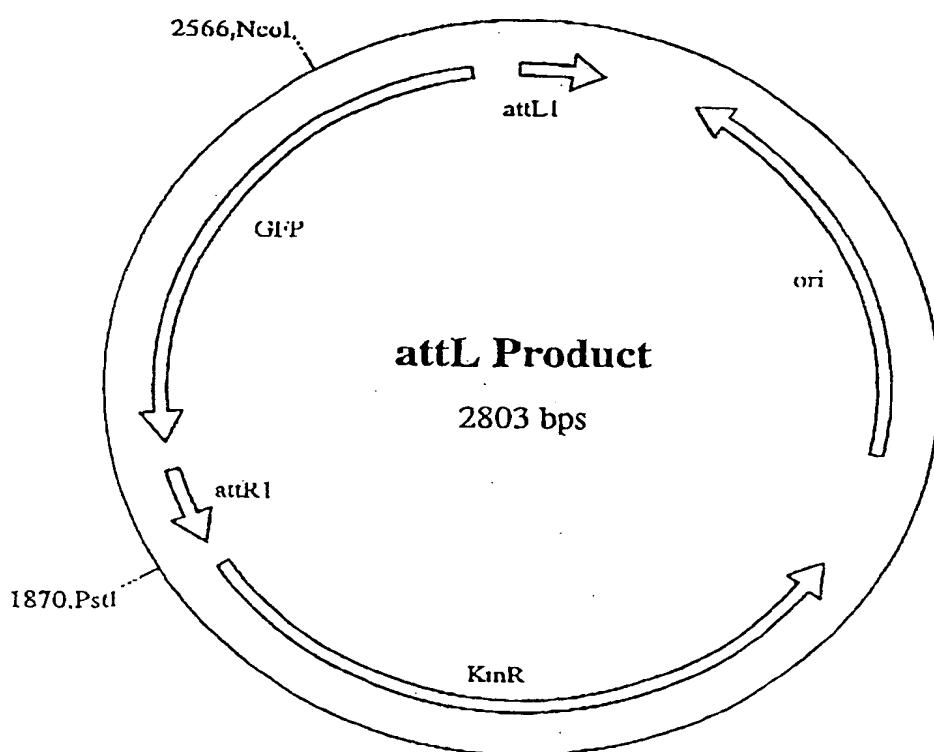
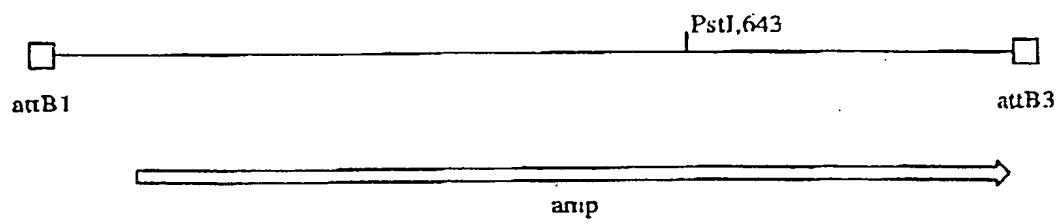
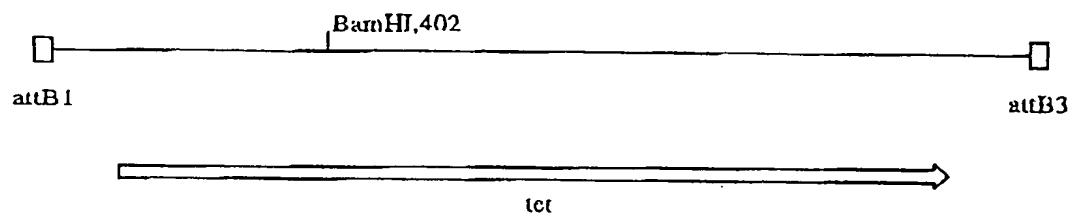


Figure 11



attB1AMPattB3 (987 bps)

Figure 12A



attB1 TET attB3 (1442 bps)

Figure 12B

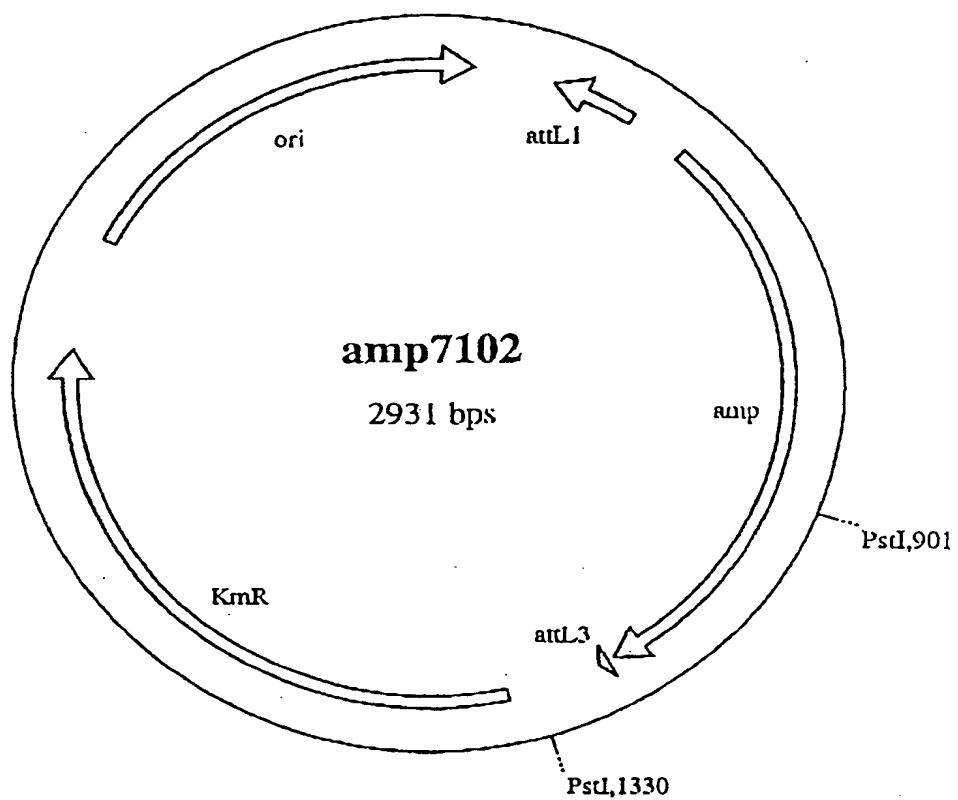


Figure 12C

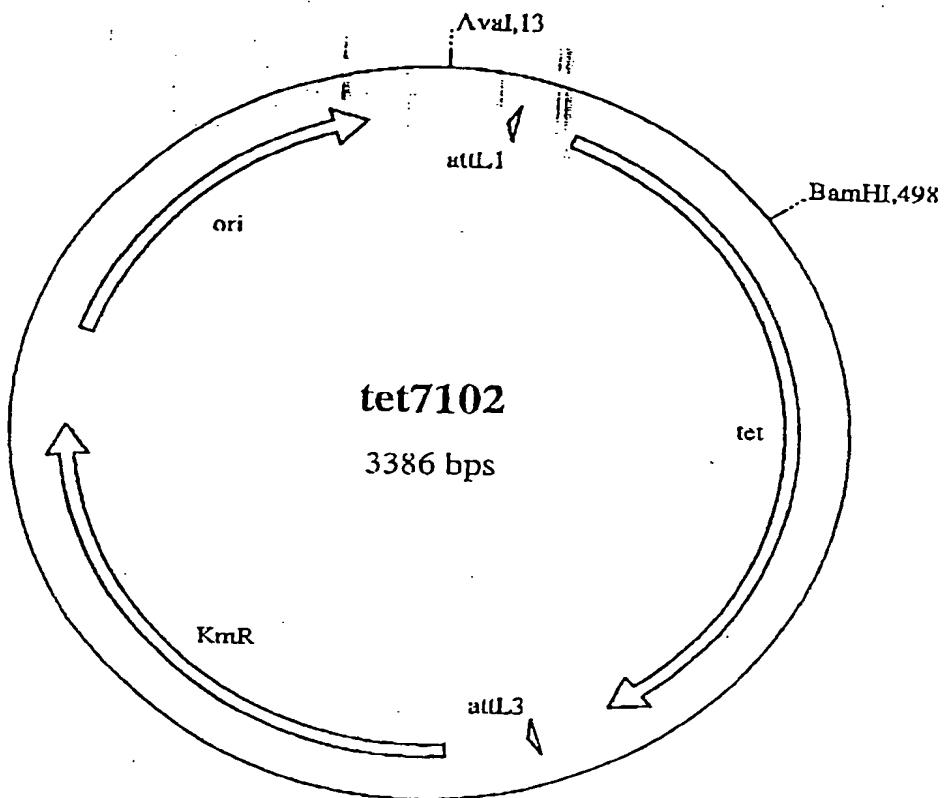


Figure 12D

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<130> 0942.285PC04

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-2-

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products

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products

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products

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products

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products

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products

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products

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products

<400> 11

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25

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products

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products

<400> 13

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<212> DNA

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<220>

<223> Description of Unknown Organism: recombination
products

<400> 14

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<210> 15

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<223> Description of Unknown Organism: recombination
products

<400> 15

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<210> 16

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<213> Unknown

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<223> Description of Unknown Organism: recombination
products

<400> 16

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25

<210> 17

<211> 39

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<213> Unknown

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products

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39

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<212> DNA

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products

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<210> 19

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oligonucleotide

-7-

<400> 19
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<211> 30
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oligonucleotide

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oligonucleotide

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oligonucleotide

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<211> 32

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<211> 15

<212> DNA

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oligonucleotide

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15

<210> 26

<211> 31

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oligonucleotide

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<210> 27

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oligonucleotide

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39

<210> 28

<211> 33

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<223> Description of Artificial Sequence: synthetic
oligonucleotide

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33

<210> 29

<211> 33

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oligonucleotide

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33

<210> 30

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-10-

<211> 34
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<220>
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oligonucleotide

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34

<210> 31
<211> 58
<212> DNA
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oligonucleotide

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<210> 32
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<213> Artificial Sequence

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oligonucleotide

<400> 32
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<210> 33
<211> 20
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13

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<223> Description of Artificial Sequence: synthetic oligonucleotide

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20

<210> 34

<211> 20

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20

<210> 35

<211> 21

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<223> Description of Artificial Sequence: synthetic oligonucleotide

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21

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<223> Description of Artificial Sequence: synthetic oligonucleotide

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<210> 37

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<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 37

acaagtttgt acaaaaaaagc a

21

<210> 38

<211> 21

<212> DNA

<213> Artificial Sequence

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<223> Description of Artificial Sequence: synthetic
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<223> Description of Unknown Organism: recombination
products

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25

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-13-

<213> Unknown

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<223> Description of Unknown Organism: recombination
products

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25

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products

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25

<210> 42

<211> 25

<212> DNA

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<223> Description of Unknown Organism: recombination
products

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25

<210> 43

<211> 25

<212> DNA

<213> Unknown

<220>

<223> Description of Unknown Organism: recombination
products

-14-

<400> 43

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25

<210> 44

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<223> Description of Unknown Organism: recombination
products

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25

<210> 45

<211> 25

<212> DNA

<213> Unknown

<220>

<223> Description of Unknown Organism: recombination
products

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25

<210> 46

<211> 25

<212> DNA

<213> Unknown

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<223> Description of Unknown Organism: recombination
products

<400> 46

tcggacgaaa gaacatgttt gaaca

25

<210> 47

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<211> 25
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products

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25

<210> 48
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oligonucleotide

<400> 48
aattctcatg tttgacagct tatac

24

<210> 49
<211> 21
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<213> Artificial Sequence

<220>
<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 49
cgatggatat gttctgccaa g

21

<210> 50
<211> 49
<212> DNA
<213> Artificial Sequence

-16-

<220>

<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 50

acaagtttgt acaaaaaagc aggctaattc tcatgtttga cagcttatac

49

<210> 51

<211> 46

<212> DNA

<213> Artificial Sequence

<220>

<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 51

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46

<210> 52

<211> 53

<212> DNA

<213> Artificial Sequence

<220>

<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 52

ggggacaagt ttgtacaaaa aagcaggcta attctcatgt ttgacagctt atc

53

<210> 53

<211> 50

<212> DNA

<213> Artificial Sequence

<220>

<223> Description of Artificial Sequence: synthetic
oligonucleotide

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ggggaccact ttgtacaaga aagctgggtc gatggatatg ttctgccaag

50

-17-

<210> 54
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<212> DNA
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<220>
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oligonucleotide

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aatacattca aatatgtatc cgcc

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<210> 55
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<212> DNA
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<220>
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22

<210> 56
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<212> DNA
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<220>
<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 56
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48

<210> 57
<211> 47
<212> DNA

-18-

<213> Artificial Sequence

<220>

<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 57

accacatgtt acaagaaagc tgggtttacc aatgcttaat cagttag

47

<210> 58

<211> 52

<212> DNA

<213> Artificial Sequence

<220>

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oligonucleotide

<400> 58

ggggacaagt ttgtacaaaa aagcaggcta atacattcaa atatgtatcc gc

52

<210> 59

<211> 51

<212> DNA

<213> Artificial Sequence

<220>

<223> Description of Artificial Sequence: synthetic
oligonucleotide

<400> 59

ggggaccact ttgtacaaga aagctgggtt taccaatgct taatcagtga g

51

<210> 60

<211> 25

<212> DNA

<213> Unknown

<220>

<223> Description of Unknown Organism: recombination

-19-

products

<400> 60

agcctgcttt tttatactaa cttga

25

INDICATIONS RELATING TO A DEPOSITED MICROORGANISM
(PCT Rule 13bis)

A. The indications made below relate to the microorganism referred to in the description on pages 35 line 31 and 36 line 1.

B. IDENTIFICATION OF DEPOSIT

Further deposits are identified on an additional sheet

Name of depository institution

Agricultural Research Culture Collection (NRRL)

Address of depository institution (*including postal code and country*)

1815 N. University Street

Peoria, Illinois 61604

United States of America

Date of deposit

October 14, 1997

Accession Number

NRRL B-21852

C. ADDITIONAL INDICATIONS (*leave blank if not applicable*)

This information is continued on an additional sheet

Escherichia coli (DB2 RR1 gyrA462, endA)

In respect of those designations in which a European Patent is sought a sample of the deposited microorganism will be made available until the publication of the mention of the grant of the European patent or until the date on which the application has been refused or withdrawn or is deemed to be withdrawn, only by the issue of such a sample to an expert nominated by the person requesting the sample (Rule 28(4) EPC).

D. DESIGNATED STATES FOR WHICH INDICATIONS ARE MADE (*if the indications are not for all designated States*)

E. SEPARATE FURNISHING OF INDICATIONS (*leave blank if not applicable*)

The indications listed below will be submitted to the International Bureau later (*specify the general nature of the indications, e.g., "Accession Number of Deposit"*)

For receiving Office use only

This sheet was received with the international application

Authorized officer

For International Bureau use only

This sheet was received by the International Bureau on:

Authorized officer